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NIST CENTENNIAL

Celebrating One Hundred Years of Chemistry at the National Institute of Standards and Technology

Chemical Science and Technology Laboratory

NIST
National Institute of Standards and Technology
Technology Administration
U.S. Department of Commerce

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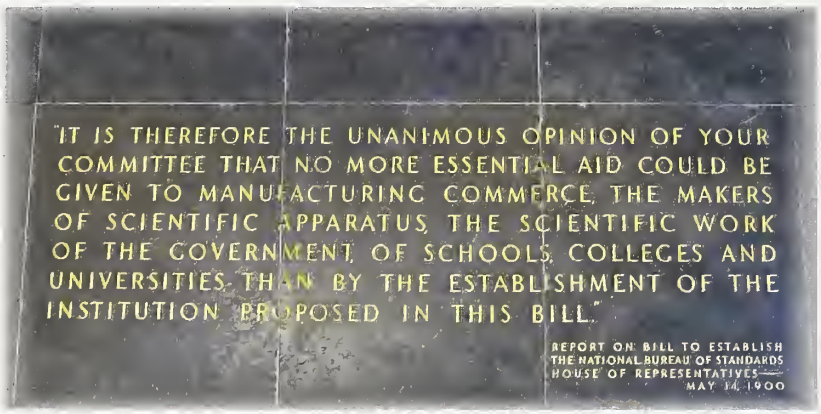
Welcome to the
National Institute of Standards and Technology

"Upon entering the Administration Building of the NIST Gaithersburg site, the feeling of spacious aesthetic design is not lost. The large reception area is flooded in black terrazzo, and its walls are white or black marble. When entering one sees on the far wall an inscription taken from a House Committee report on the bill to establish the Bureau, dated May 14, 1900. In gold letters, incised into black marble, the quotation states:


"IT IS THEREFORE THE UNANIMOUS OPINION OF YOUR COMMITTEE THAT NO MORE ESSENTIAL AID COULD BE GIVEN TO MANUFACTURING COMMERCE, THE MAKERS OF SCIENTIFIC APPARATUS, THE SCIENTIFIC WORK OF THE GOVERNMENT, OF SCHOOLS, COLLEGES AND UNIVERSITIES THAN BY THE ESTABLISHMENT OF THE INSTITUTION PROPOSED IN THIS BILL."
REPORT ON BILL TO ESTABLISH THE NATIONAL BUREAU OF STANDARDS HOUSE OF REPRESENTATIVES MAY 14, 1900

It forms an impressive greeting."

Excerpt from: *A Unique Institution, The National Bureau of Standards, 1950 – 1969*
Elio Passagalia, Editor
U.S. Government Printing Office, Washington DC

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Celebrating One Hundred Years of Chemistry at the National Institute of Standards and Technology

Chemical Science and Technology Laboratory

September 2000

U. S. DEPARTMENT OF COMMERCE
Norman Y. Mineta, Secretary

TECHNOLOGY ADMINISTRATION
Dr. Cheryl L. Shavers, Under Secretary of Commerce for Technology

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
Raymond G. Kammer, Director

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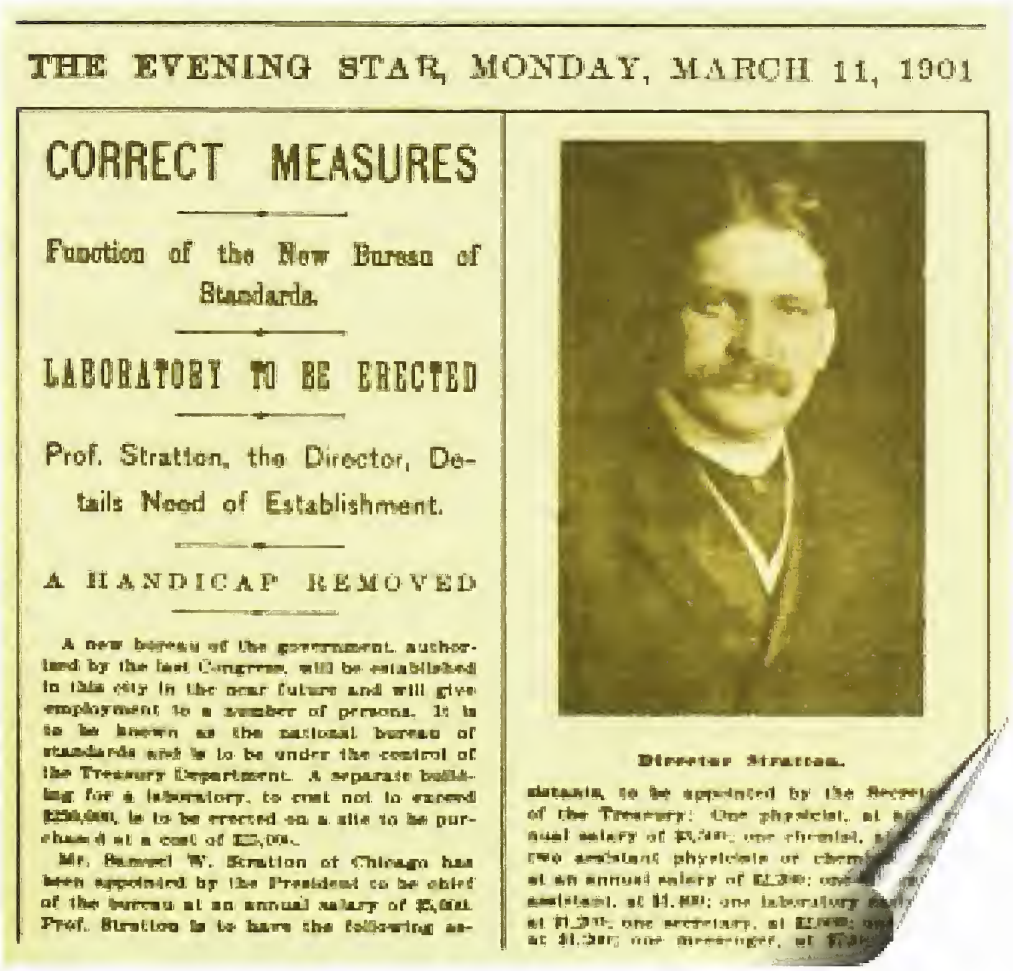
Version of January, 2001

National Institute of Standards and Technology
The Centennial Celebration

from 1901 ...

to 2001 ...

Since its creation in 1901, the National Institute of Standards and Technology has been the source of measurements and standards on which U.S. manufacturing, commerce, scientific institutions and all branches and levels of government depend. NIST will celebrate its centennial on March 3, 2001.



THE EVENING STAR, MONDAY, MARCH 11, 1901

CORRECT MEASURES

Function of the New Bureau of Standards.

LABORATORY TO BE ERECTED

Prof. Stratton, the Director, Details Need of Establishment.

A HANDICAP REMOVED

A new bureau of the government, authorized by the last Congress, will be established in this city in the near future and will give employment to a number of persons. It is to be known as the national bureau of standards and is to be under the control of the Treasury Department. A separate building for a laboratory, to cost not to exceed $250,000, is to be erected on a site to be purchased at a cost of $75,000.

Mr. Samuel W. Stratton of Chicago has been appointed by the President to be chief of the bureau at an annual salary of $6,000. Prof. Stratton is to have the following as-

Director Stratton.

sistants, to be appointed by the Secretary of the Treasury: One physicist, at an annual salary of $5,000; one chemist, at $5,000; two assistant physicists or chemists, at an annual salary of $1,200; one assistant, at $1,400; one laboratory assistant, at $1,200; one secretary, at $2,000; one messenger, at $720.

Chartered by Congress, NIST (originally known as the National Bureau of Standards) was the first physical science research laboratory of the federal government. It was established at about the same time as the nation's first commercial laboratory. At that time, the United States had few, if any, absolute national standards Instead, there was a patchwork of regional standards, often arbitrary, which proved to be a burden as much as an aid to commerce. Yet, at that time, the United States was becoming a world power, with an industrial economy driven by the steam engine, the railroad and the expanding reach of electricity. Other industrialized nations already had established standards laboratories.

After strong advocacy by leading scientists and industrialists, Congress established the National Bureau of Standards. Because Lyman Gage, Secretary of the Treasury under President McKinley, initiated and led the campaign for a national standardizing laboratory in the federal government, the Bureau of Standards was originally in the Treasury Department. In 1903, the new Department of Commerce and Labor was established, and the House Committee on Interstate and Foreign Commerce recommended that *"The newly created National Bureau of Standards is a bureau which necessarily goes into a department primary devoted to manufacturing and commercial interests. This Bureau is destined to exercise great influence on the development of business and commerce of our country"*. When the Commerce and Labor Department was divided, NBS went with the Commerce Department where it remains.

Industrial Central Research Laboratories established:

1900 General Electric
1903 DuPont
1904 Westinghouse
1908 Corning Glass
1912 Eastman Kodak
1925 Bell Telephone
1928 U.S. Steel

The Early Decades Both World Wars found NBS deeply involved in mobilizing science to solve pressing weapons and war materials problems. After WWII, basic programs in nuclear and atomic physics, electronics, mathematics, computer research, and polymers as well as instrumentation, standards, and measurement research were instituted.

In the 1950s NBS research helped usher in the computer age and was employed in the space race after the stunning launch of Sputnik. A second NBS campus was dedicated in Boulder CO in 1954. This new facility permitted an explosion in the number of calibrations of radio-related equipment.

In the 1960s The Bureau's technical expertise led to assignments in the social concerns of the Sixties; including the environment, health and safety. This decade saw the move of NBS laboratories from the Van Ness site in Washington DC, to the then rural Gaithersburg MD, where is it located today. By the Seventies, energy conservation and fire research had also taken a place at NBS.

The mid-to-late 1970s and 1980s found NBS returning with renewed vigor to its original mission focus in support of industry and commerce. In particular, increased emphasis was placed on addressing measurement problems in the emerging technologies.

The Omnibus Trade and Competitiveness Act of 1988 augmented the Institute's uniquely orchestrated customer-driven, laboratory-based research program aimed at enhancing the competitiveness of American industry by creating new program elements designed to help industry speed the commercialization of new technology. To reflect the agency's broader mission, the name was changed to the National Institute of Standards and Technology (NIST).

Technology Competitiveness Act
The Omnibus Trade Bill of August 23, 1988

"To modernize and restructure (NBS) to augment its unique ability to enhance the competitiveness of American industry while maintaining its traditional function as the lead national laboratory for providing measurements, calibrations and quality assurance techniques which underpin U.S. commerce, technological progress, improved product reliability and manufacturing processes and public safety."

NIST
National Institute of Standards and Technology
. . .working with industry to develop and apply technology, measurements and standards

http://www.nist.gov

Ray Kammer – Director

Karen Brown – Deputy Director

NIST's four major programs are designed to help U.S. companies achieve their own success, each one providing appropriate assistance or incentives to overcoming obstacles that can undermine industrial competitiveness. Each of the four programs addresses different components of the technology pipeline.

Measurement and Standards Laboratories

The Measurement and Standards Laboratories provide technical leadership for vital components of the nation's technology infrastructure needed by U.S. industry to continually improve its products and services. NIST's seven discipline-based Measurement and Standards Laboratories work at all stages of the pipeline from advancing basic science and pioneering new measurement methods to the development of standard test methods, materials, and data to ensure the quality of commercial products. The seven NIST Laboratories are: Electronics and Electrical Engineering Laboratory (EEEL), Manufacturing Engineering Laboratory (MEL), Chemical Science and Technology Laboratory (CSTL), Physics Laboratory (PL), Materials Science and Engineering Laboratory (MSEL), Building and Fire Research Laboratory (BFRL) and, Information Technology Laboratory (ITL).

Advanced Technology Program

The Advanced Technology Program (ATP) bridges the gap between the research lab and the market place, stimulating prosperity through innovation. Through partnerships with the private sector, ATP's early stage investment is accelerating the development of innovative technologies that promise significant commercial payoffs and widespread benefits for the nation.

Manufacturing Extension Partnership

In 1989, NIST established the first federally funded extension centers to help small manufacturers improve their capabilities and performance—a necessity for survival in the global marketplace. Today, the Manufacturing Extension Partnership is a nationwide network of more than 400 not-for-profit centers and field offices that, in 1999, provided technical assistance to nearly 27,000 smaller manufacturers. MEP makes it possible for even the smallest firms to tap into the expertise of knowledgeable manufacturing and business specialists all over the U.S.

Baldrige Quality Program

The Baldrige Quality program is an outreach program associated with the Malcolm Baldrige National Quality Award that recognizes business performance excellence and quality achievement by U.S. manufacturers, service companies, educational organizations, and health care providers. The Malcolm Baldrige National Quality Award, created in 1987, is widely credited with making quality a national priority.

U.S. Dept. of Commerce
Technology Administration

Chemical Science and Technology Laboratory

http://www.cstl.nist.gov/

Hratch Semerjian – Director

William Koch – Deputy Director

The Chemical Science and Technology Laboratory is one NIST's Measurements and Standards Laboratories. Reflecting the importance of chemical measurements and standards to our country, the Chemistry Division was one of the first established by the founders of NBS/NIST in 1901.

Building on a one hundred year history of technical excellence, today's Chemical Science and Technology Laboratory has the most comprehensive array of chemical, physical and engineering measurement capabilities of any group working in chemical science and technology.

CSTL's ***vision*** is to be a world-class research laboratory that is recognized by the nation as the primary source for the chemical, biochemical, and chemical engineering measurements, data, models, and reference standards that are required to enhance U.S. competitiveness in the world market.

As the nation's chemical reference laboratory, CSTL's ***mission*** is to provide the chemical measurement infrastructure to enhance U.S. industry's productivity and competitiveness, assure equity in trade, and improve public health, safety and environmental quality. An important part of CSTL's efforts is to access future measurement needs through interaction with a broad base of customers and through extensive ties to industry, academia and other government agencies.

CSTL seeks to accomplish this mission by setting and meeting the following ***goals***:
Measurement Standards: Establish CSTL as the pinnacle of the national traceability and international comparability structure for measurements in chemistry, chemical engineering, and biotechnology, and provide the fundamental basis of the nation's measurement system.
Chemical and Process Information: Assure that U.S. industry has access to accurate and reliable data and predictive models to determine the chemical and physical properties of materials and processes.
Measurement Science: Address current, and anticipate next-generation, measurement needs of the nation by performing cutting-edge research in measurement science.

Chemistry at NBS/NIST is steeped with rich traditions and established partnerships with industry and academia. While the nature of the partnerships may change with societal expectations of the time, the dedication to addressing industry needs remains a hallmark of the institution. Certainly chemical science has evolved over the past century and enabled many new technologies. This book describes our present activities with a historical perspective, in hopes of providing insights into the years to come.

Our Customers ... You

... responsive and responsible service
to industry, academia, and other agency partners
for the American people and the broader global community ...

CSTL is a multifaceted, synergistic organization with a broad customer base. The Laboratory has technical capabilities in analytical chemistry, surface chemistry and microanalysis, chemical and physical properties, process measurements and modeling, and biotechnology. Its core competencies in physical and chemical measurement standards, data, and science are its strength and are the source of its unique contribution to technological development. These core competencies are not stagnant, but rather evolve and change and have become an integral part of advancing technology. These competencies both influence advances and are influenced by them.

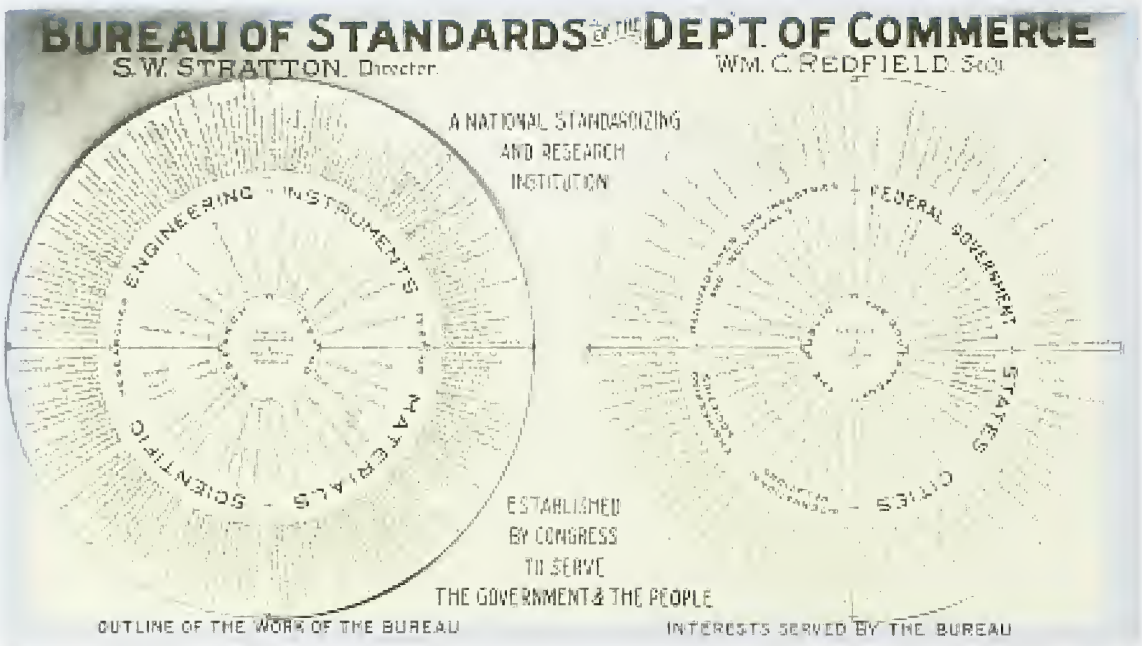
CSTL's core competencies support its programs. These programs are a reflection of our customer needs. This basic philosophy is depicted in the figure below.

CSTL Programs Support a Diverse Customer Base

The **primary customers** we serve are: industry (chemical, electronics/microelectronics, automotive and transportation, energy, petrochemical, instrumentation, metals and materials, biotechnology, environmental technologies, food, health care and pharmaceutical); federal, state, and local government agencies. We also serve standards and industrial trade organizations, and the academic and scientific communities.

To meet these customer needs CSTL currently has the following **programs**: chemical characterization of materials, environmental measurements, atmospheric chemistry, food and nutrition, clinical measurements, structural biology and bioinformatics, DNA technologies, chemical and biochemical data, physical properties data, combinatorial methods, nanotechnology, process metrology, process engineering, chemical and biochemical sensing, semiconductor metrology, thin films and interfaces, and international physical and chemical measurement standards.

Identifying and defining our customer base, and articulating our services and programs while reaffirmed in the present day, are not new to NIST. This is evidenced by the "Activity Wheel" (below) constructed during the early days.



"The proliferation of Bureau interests, abetted by special congressional appropriations for investigations not covered in the Organic Act, inspired the wheeled chart of NBS activities. It was probably prepared for an appropriations hearing before congress about 1915." ***Measures for Progress – A History of NBS, published in 1966 by NBS and DoC.***

Budgetary Issues:

Proposal Bill for Staffing the newly founded NBS – Lyman Gage, Secretary of the Treasury – 1900

Position	Annual Salary
Director	$6000
One Physicist	$3500
One Chemist	$3500
Two Assistants (Physicists or Chemists)	$2200 each
Two Laboratory Assistants	$1400 each
Two Others	$1200 each
One Secretary	$2000
Two Clerks	$1400, and $1000
One Messenger	$750
One Engineer	$1500
One Fireman	$720
Three Mechanicians	$1400, $1000, and $840
One Watchman	$720
Two Laborers	$600 each

Historical note:

Final appropriations cut back salary schedule by reducing director's salary to $5000 and eliminating 8 of the 21 proposed positions, including the two laboratory assistants, the secretary, a clerk, the fireman, 2 mechanicians, and a laborer.

The sum for equipping the main laboratory was reduced from $25,000 to $10,000

... And at the turn of the millennium ...

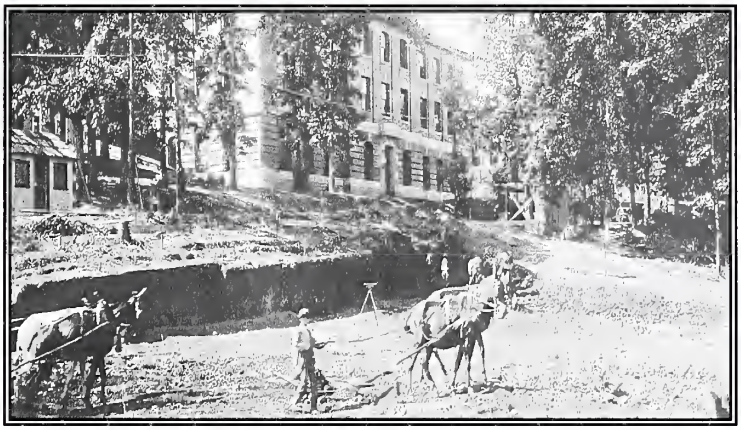
NIST's Budget: ***$800 million (operating budget from all sources)***

Staff: ***3,300 scientists, engineers, technicians, business specialists, and administrative personnel. In addition, about 1,500 visiting researchers complement the staff. NIST also partners with 2,000 manufacturing specialists and staff at affiliated centers around the country.***

Chemistry Laboratories at NBS/ NIST: then and now

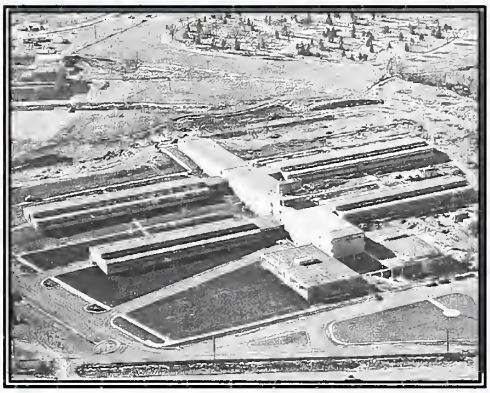
Facilities and Locations: By 1903, construction of the new laboratory facilities were underway. The site selected was a then sparsely populated and remote residential section on Connecticut Avenue to the north of the business center of Washington DC.

The first World War prompted the expansion of NBS. Chemicals and steels, used in weapon production, were the primary concerns of the Bureau throughout the war. Under the stimulus of war, industry turned out scores of new alloy steels – containing nickel,



chromium, tungsten, zirconium, molybdenum, vanadium, manganese, and cobalt – and sent them to the Bureau for chemical composition analysis and properties determinations. Groundbreaking for a new chemistry building was in early fall 1915, with full occupation of the then state-of-the-art laboratory in 1917.

The Boulder Site:



The Boulder Laboratories were formed by the National Bureau of Standards in the early 1950's when radio research was moved out of the Washington, D.C. area. President Eisenhower dedicated them on September 14, 1954. Even before that date, however, work had begun at the Boulder Labs. Working for the old Atomic Energy Commission (AEC), NBS had established a hydrogen production facility on site in conjunction with the hydrogen bomb project at Los Alamos, NM. Within a short time, the AEC decided to go in a different direction and did not need liquid hydrogen from NBS. However, this capability led to the formation of the Cryogenic Engineering Division. So, for many years the Boulder Labs specialized in radio propagation physics, radio propagation engineering, radio standards, and cryogenics.

Current areas of research include time standards, optical fibers, antenna measurements, superconducting electronics, wireless communication, magnetics, advanced materials, semiconductors, optoelectronics, physical and chemical properties, alternative refrigerants, information technology, and quantum physics.

The Gaithersburg Site: The NBS facilities on the Van Ness site served the country well for more than fifty years. However, by 1955 it was clear that the physical plant suffered greatly … and plans were initiated to relocate to a site near the then "small, sleepy town of Gaithersburg". Preservation of the NBS culture was articulated in letter to the mayor of Gaithersburg in 1956:

"The Bureau wishes to develop on its new site a university campus-type atmosphere similar to the one which had been achieved on the present site. It has been found that such surroudings are an asset in attracting and maintaining scientists and in producing the environment which stimulates scientific productivity".

NIST Gaithersburg Campus, Spring 2000

New facilities mark the new millennium:

Fully occupied in May 1999 NIST's ***Advanced Chemical Science Laboratory*** is a state-of-the-art research facility that provides the means to meet 21st century needs in pharmaceutical manufacturing, medical diagnostics, pollution monitoring and clean-up, nutritional analysis, and advanced materials research. The building features high-efficiency air handling, precise temperature and humidity control, an uninterruptible power supply, an emergency back-up generator, and a wiring backbone that will satisfy data transmission needs well into the future.

The ground-breaking for the new ***Advanced Measurement Laboratory*** (AML) took place in June 2000. Expected to be ready for occupancy in 2004, the AML will enable CSTL and NIST to keep pace with the rapid developments in emerging technologies requiring molecular and atomic-level precision.
AML will provide improved power quality and stringent controls on:

- Air quality - Class 10,000 Building, Class 100 Clean Rooms
- Temperature - controlled to ± 0.25 °C in Instrument Labs, ± 0.1 °C and ± 0.01 °C in Metrology Labs
- Vibration - <3μm/sec
- Humidity - 40% ± 1%

Measurements and Standards: from the early 1900's to the new millennium

Physical Standards: thermometry over the years

NBS 1901 - Division I
Heat and Thermometry
"As primary standards, this section had acquired a number of specially constructed ... thermometers in Europe, and was prepared to certify almost any precision thermometer used in scientific work, as well as industrial and commercial thermometers."

... and the rest is history...
The Bureau's first director was reluctant to hire women since "the sight of his scientists in shirtsleeves might offend them." However, almost 100 women came to the Bureau during the war, making significant contributions in many technical areas. ... Among them was Miss Johanna Busse, a researcher in *thermometry*, who in 1929 became the chief of the section until her retirement in 1949."
Measures for Progress – A History of NBS

International temperature scale had its inception in 1911 when the national laboratories of Great Britain, Germany, and the United States proposed to adjust the differing "practical" temperature scale to absolute. This proved more difficult than anticipated, and in 1927, the three laboratories proposed adoption of an "international temperature scale" (ITS) that might be more readily realized. This practical temperature scale ranged from the temperature of liquid oxygen to that of luminescent incandescent bodies – serving the immediate needs of industry. Agreement on the basic fixed point was reached a year later. For the first time it became possible to certify temperature measurements for a wide variety of industrial purposes. The international temperature scale has been updated and amended in several times during the past century.

History of Temperature Scales:

1. The normal hydrogen scale (adopted in 1889)
2. The International Temperature Scale of 1927 (ITS-27)
3. The International Temperature Scale of 1948 (ITS-48)
4. The International Practical Temperature Scale of 1948, amended edition of 1960 IPTS-48(60)
5. The International Practical Temperature Scale of 1968 (IPTS-68)
6. The International Practical Temperature Scale of 1968, amended edition of 1975 IPTS-68(75)
7. The 1976 Provisional 0.5 K to 30 K Temperature Scale (EPT-76), adopted in 1979
8. The International Temperature Scale of 1990 (ITS-90)

NIST First to Realize International Temperature Scale (ITS-90) from 0.65 K to 1234.94 K with uncertainties (<0.1 to 1.1 mK)

Dissemination of ITS-90

- **Calibration of precision resistance thermometers**
- **Extensive use of SRMs**
  - **Fixed-point cells**
  - **High purity metals**
  - **Reference thermometers**

Customers

- **Aerospace**
- **Cryogenic fuel industries**
- **Academia**
- **Other agency sponsors**

Cutting-edge research in thermometry for the next generation temperature scale

Acoustic Thermometry takes advantage of the fact that the speed of sound of a monatomic gas is simply related to the thermodynamic temperature. The speed of sound is measured via acoustic techniques in a basketball-sized spherical shell. The acoustic resonator shown is resting inside half of a spherical 3 L pressure vessel and furnace cell.

Acoustic thermometry promises to improve the accuracy of thermodynamic temperature measurements above 500 K by a factor of five. These measurements will provide the basis for the next international temperature scale, and an improvement in the consistency of thermometer calibrations.

NIST's calibration services link the makers and users of precision instruments to basic and derived units of the International System (SI) of units. As one of the cornerstones for ensuring the consistency of measurements in the United States and internationally, this measurement transfer system is a critical factor in controlling manufacturing, assembly processes, and marketing, as well as assuring the quality of manufactured goods. Users of these services send transfer standards to NIST where they are calibrated according to a measurement process that is stable, predictable, and statistically analyzed. Currently NIST provides more than 500 different calibrations, tests, and measurement quality assurance programs in seven major measurement areas.

CSTL partners with NIST's Technology Services and provides calibration services for the following:

- **Thermometers (including thermocouples)**
- **Humidity Measuring Instruments**
- **Air Speed Instruments**
- **Volumetric Test Measures**
- **Pressure and Vacuum Gauges**
- **Fluid Flow Meters**
- **Optical Filters**

http://ts.nist.gov/ts/htdocs/230/233/calibration/index1.html

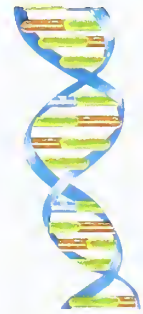
Chemical Standards: addressing needs of mature and emerging industries

The Bureau's First Standard Samples (1905)

"Standard Samples" (with chemical properties certified) were first sold by the Bureau in **1905** when it undertook to certify and distribute the composition of various types of iron provided by the **American Foundrymen's Association.** In **1906**, at the request of the **Association of American Steel Manufacturers,** the Bureau began the preparation and certification of samples of seventeen types of steel, and thus the Standard Samples Program was born.

By **1951**, the Bureau had a whole catalogue of 502 standard samples, with 98 of these samples of steel that were certified for the concentration of up to ten elements. Another 224 samples were hydrocarbons and organic sulfur compounds produced with the help of the **American Petroleum Industry** for the analysis of process streams in petroleum refineries.

New Standards for New Technologies: Human Identity Testing has captured the interest of molecular biologists, as well as the public, since the late 1980's. NIST/CSTL's involvement in this developing technology for the nation's crime laboratories has resulted in a robust and widely accepted discipline today.

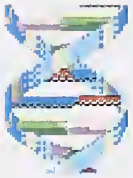


> "The general quality of DNA fingerprinting evidence currently being introduced into U.S. courts appears to be quite mixed," Eric S. Lander, a Harvard University research professor, told a House subcommittee in March 1992, "largely due to an absence of rigorous accepted standards."

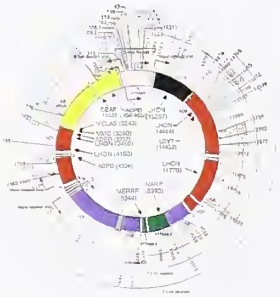
To address the principle areas of need for measurement standards in DNA testing, the **first NIST DNA Profiling Standard** was completed and released in the fall of 1992. This Standard Reference Material (SRM 2390) was a DNA profiling standard developed to include existing *de facto* standards such as the female cell line, K562. The SRM was recognized as one of that year's top 100 technological advances, with a prestigious R&D 100 Award in 1993.

The first Polymerase Chain Reaction (PCR)-based DNA profiling Standard Reference Material, SRM 2391, was released in June 1995. This SRM was developed to support the rapid advances in PCR-based technologies in the early 1990's. SRM 2391 was the first standard available that supplied DNA material with multiple loci and genetic typing information. Within a short time, SRM 2391 was enhanced to support the newly developed Short Tandem Repeat (STR) genetic systems for DNA profiling. An extensive set of STR data for the cell lines and genomic DNAs were added to include new forensic markers available from commercial laboratories. This was

done to comply with requests from the FBI and other forensic laboratories to have the SRM 2391 certificate updated to include all genomic DNA components for these tests. NIST has also developed a website (STRBase) to provide a single site where STR information can be obtained by users.



STRBase
http://www.cstl.nist.gov/div831/



The latest release in the suite of DNA Standards:
Human Mitochondrial DNA Standard Reference Material (SRM 2392). This SRM is used in quality control, in sequencing, forensic identification, medical diagnostics and mutation detection. The SRM includes extracted DNA and all information for performing PCR amplification process, cycle sequencing steps, gel preparation, data analyses to determine DNA sequence, and materials to assess the accuracy of the results. In addition, sequences of 58 sets of unique primers are also included to allow any area of all mtDNA to be amplified and sequenced.

Today, CSTL partners with the NIST Technology Service's **Standard Reference Materials Program** to provide scientists and engineers in industrial and academic research with internationally accepted SRMs for critical technical decision-making. NIST pioneered, and continues to lead, in the development of certified reference materials used for quality assurance. NIST provides more than 1,200 different SRMs certified for specific chemical composition or physical properties. CSTL provides technical leadership for most of the chemical and compositional standards produced by NIST.

SRMs are used for three main purposes: to help develop accurate methods of analysis (reference methods); to calibrate measurement systems; and to assure the long-term adequacy and integrity of measurement quality assurance programs. NIST SRMs also legally constitute part of the National Measurement System infrastructure of the United States and, as such, are essential transfer mechanisms for national as well as international measurement traceability. SRMs are available for many applications, including: engine wear materials, environmental materials, ferrous and non-ferrous metals, food and agriculture, fossil fuels, gas mixtures, geological materials, high-purity materials, health/clinical/industrial hygiene, microanalysis, optical and thermophysical properties. The complete list of available SRMs can be found on the following web site.

http://ts.nist.gov/ts/htdocs/230/232/232.htm

Standard Reference Data

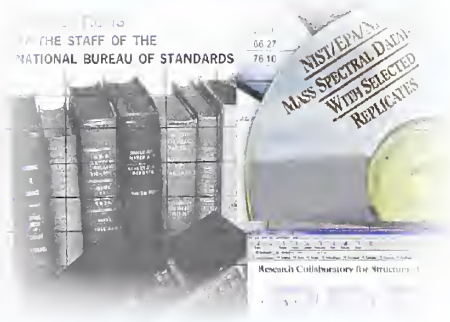
"In 1909 the American Society of Refrigeration Engineers, in search of physical data for more efficient refrigeration, asked the Bureau to determine the specific heats of several calcium chloride brines." And so it began … ***(Measures for Progress – The History of NBS)***

NIST DATA The NIST Standard Reference Database (SRD) series has grown to over 50 electronic databases in chemistry, physics, materials, building and fire research, software recognition, and electronics. Versatile interactive databases provide easy access to high quality NIST data. Traditionally, CSTL has been the key source for evaluated data and Standard Reference Data. Through this program CSTL provides SRDs for Analytical Chemistry, Atomic and Molecular Physics, Biotechnology, Chemical and Crystal Structure, Chemical Kinetics, Industrial Fluids and Chemical Engineering, Materials Properties, Surface Data, and Thermodynamics and Thermochemistry. Methods of data dissemination have changed dramatically over the last century – from tables in voluminous books to computer disks and the World Wide Web.

http:///www.nist.gov/srd/

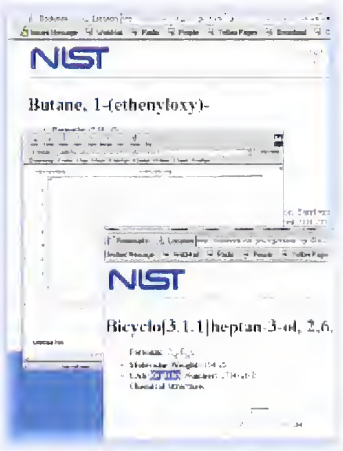
IR Spectral Data – *what goes around comes around*

In 1905, the NBS IR Specta program was established by William Coblentz, and the first book of spectra was published in 1910. By mid-century the IR Spectra resided with the Coblentz society. However, in the late 90's the data was returned to NIST and is being prepared for web-based dissemination.



CSTL led the efforts to provide the mass spectral community with a fully evaluated mass spectral database. **NIST/EPA/NIH Mass Spectral Library** was first published in 1976 in three volumes with three supplements. It is currently disseminated via CD and the Web and is installed on more than 3000 mass spectrometers annually. It contains evaluated spectra for more than 100,000 compounds and it is continually updated with the addition of high quality data.

The NIST Chemistry WebBook, now in its 6th edition, was first released in 1996. In addition to the abundance of thermochemical, thermophysical, and ion energetics data, the new release of February 2000 contains Henry's Law data, UV/Visible Spectral data, and new data on critical constants such as Vapor Pressure and Ion Energetics. In addition, there has been data expansion in areas that support chemical design, including; thermochemical and thermophysical properties of pure fluids and aqueous solutions, vapor-liquid equilibrium data, and equation of state information.



http://webbook.nist.gov

User Statistics:

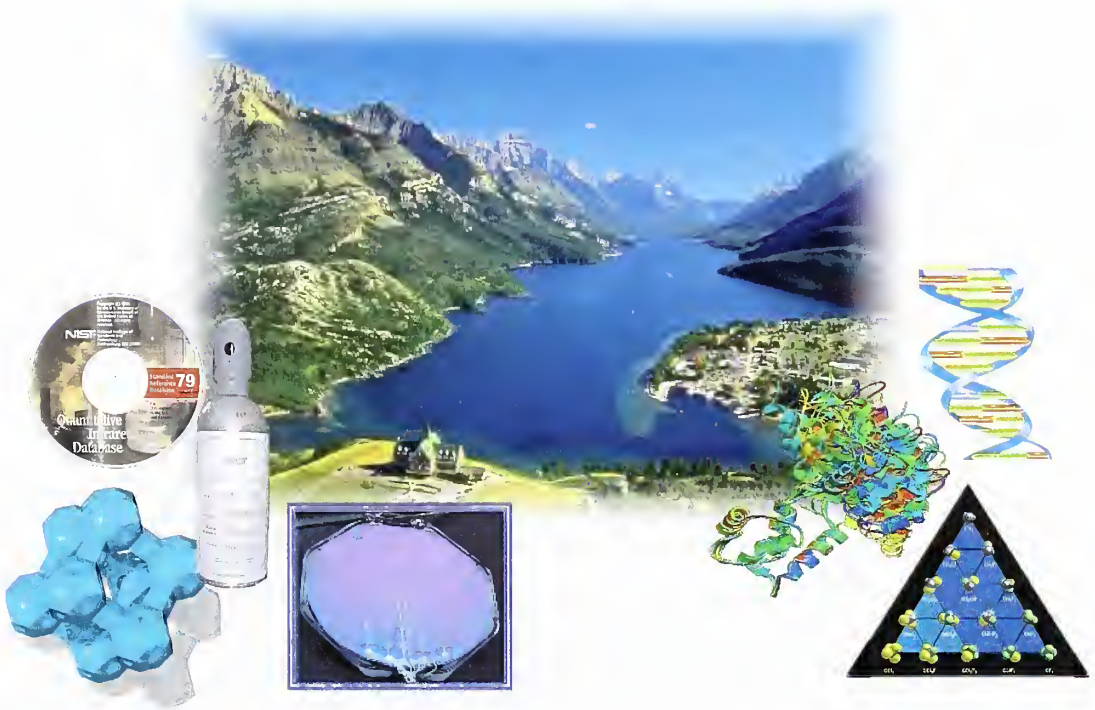
- **Between 6000 and 12000 users per week**
- **45-55% are return users**

New tool **for sub-structure searching for chemical structures drawn by user**

Selected Activities

The following pages describe selected areas of activity for CSTL. These are:

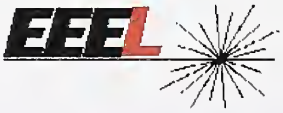
1. *Biotechnology*
2. *Catalysis and Biocatalysis*
3. *Green or Sustainable Chemistry*
4. *Nanotechnology*

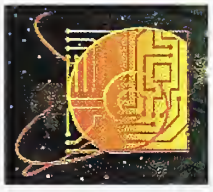


Multi-discipline, synergistic teams are required to address the needs of modern technology. To this end CSTL partners with all other NIST Measurements and Standards Laboratories.

Building and Fire Research (BFRL)
http://www.bfrl.nist.gov/

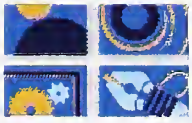
Electronics and Electrical Engineering Laboratory (EEEL)
http://www.eeel.nist.gov/





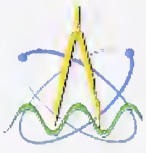
Information Technology Laboratory (ITL)
http://www.itl.nist.gov/

Manufacturing Engineering Laboratory (MEL)
http://www.mel.nist.gov/



Materials Science and Engineering Laboratory (MSEL)
http://www.msel.nist.gov/

Physics Laboratory
http://www.pl.nist.gov/



CSTL supports NIST's ATP to accelerate the development of innovative technologies for broad *national benefit* through *partnerships* with the *private sector*

Biotechnology

"Certainly all Americans can enjoy the benefits from the huge advances being made in biotechnology; those include improved human health ... improved agriculture... and improved industrial productions ..."

Carl B. Feldbaum, President, Biotechnology Industry Organization

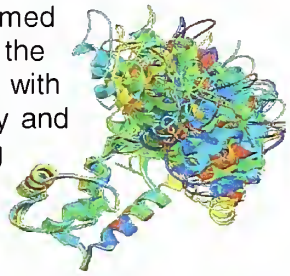
CSTL provides new standards, evaluated reference data, and new measurement technology for a growing field.

Protein Data Bank

Research Collaboratory for Structural Bioinfor

PROTEIN DATA BANK

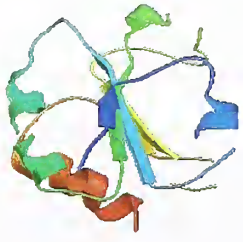
The Protein Data Bank (PDB) is the single most comprehensive international repository for the processing and distribution of 3-D structure data of biological macromolecules dtermined experimentally by Nuclear Magnetic Resonance (NMR) and X-ray crystallography.



The Research Collaboratory for Structural Bioinformatics assumed responsibility for the PDB in 1998. This consortium includes NIST, the University of California at San Diego, and Rutgers University. This team, with expertise in structural biology, data processing and validation, and query and visualization tool development, was charged with the task of compiling existing structural data in a uniform format and developing software for collecting new structures, assessing the reliability of these data, and distributing these evaluated structures.

At present, over 13,000 fully evaluated structures are available through the PDB. These data can be searched using nineteen different parameters encompassing chain type, sequence, secondary structure, crystallographic parameters, compound formula, and bibliographic information. New search fields are constantly being added, as these additional fields are validated and the software is enhanced.

Another key component of this system is the ability of researchers to contribute new structures to this archive. The system collects data using a unified data set and vocabulary. These data are then validated by comparing bond distances against typical values, chiral centers are checked for correct stereochemistry, sequences are compared and nomenclature verified. Finally, with the contributor's permission, the structure is added to the database.



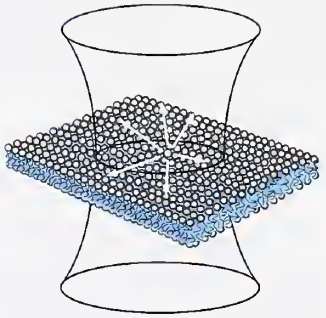
The utility of this archive is evident in its growth and use. During the first quarter of this year, over five-hundred new structures were deposited. During a typical month, there are about two million hits, and an average of one structural query per minute. These numbers grow monthly.

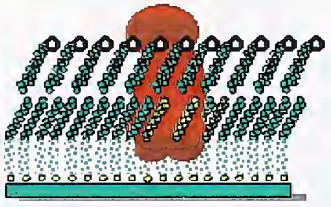
GENETIC ENGINEERING GEN NEWS **PDB Web Site is among the 50 most influential and important biotechnology Web Sites in 1999**

http://nist.rcsb.org

Optically Interrogating Single Molecules in Bilayer Membranes

A new measurement technology that combines single-molecule fluorescence spectroscopy with single ion-channel electrophysiology is under development. The technique will enable the structure and function of individual membrane-incorporated molecules to be simultaneously interrogated with light and electricity in real time. As a first step toward this long-range goal, a highly sensitive scanning confocal fluorescence microscope was coupled to a planar lipid bilayer apparatus, allowing basic optical studies on the behavior of fluorescently labeled lipids at the single molecule level to be conducted.

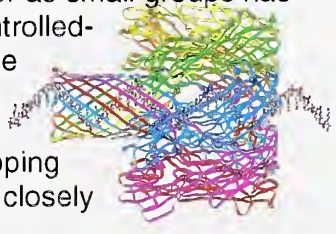




Quantification of single-molecule Brownian motion in lipid bilayers has the potential to yield the most accurate diffusion measurements possible. Traditional techniques, such as fluorescence photobleaching and recovery, nuclear magnetic resonance, and electron spin resonance require a relatively high label concentration (typically 0.1-1%) to generate a sufficient signal-to-noise ratio. The disturbances caused by the presence of the label can contribute to varying results for diffusion measurements performed with different techniques on the same membrane system. Experiments employing single-molecule instrumentation enable measurements to be conducted at a much reduced label concentration (below 0.00005%); thus, label-induced perturbations are virtually eliminated.

Diffusion measurements reveal a surprisingly large optical trapping potential on single molecules. At low photon flux (~10 kW/cm^2), an optical trapping effect appears that is ~5 x 10^6 larger than theory predicts for single lipid molecules in solution and 100 times larger than predicted for lipids in a bilayer. Interestingly, at moderate excitation powers (~300 kW/cm^2), the laser is capable of guiding the diffusive motion of individual fluorophores as the beam scans across the membrane plane.

These findings have significant implications for a variety of techniques that apply large optical gradients to membranes. In the past, confocal microscopy has been widely used to study ensembles of fluorescent molecules in cells and membranes. The technique has only recently (1999) been applied to the study of membrane-kinetics at the single-molecule level. In order to make accurate diffusion measurements in cells or model membranes, precautions must be taken to avoid the apparent perturbations (e.g., photobleaching and optical trapping) caused by high optical fields. Additionally, the ability to guide molecules individually or as small groups has exciting implications for nanofabrication, membrane patterning, and controlled-release drug delivery. In the future, it might be possible to enhance the trapping effect by using molecules with multiple fluorescent labels, or labels with improved photostability. This type of optical "handle" would be orders of magnitude smaller than that currently used for optical trapping and manipulation and would allow the molecule under control to more closely approximate its native behavior.

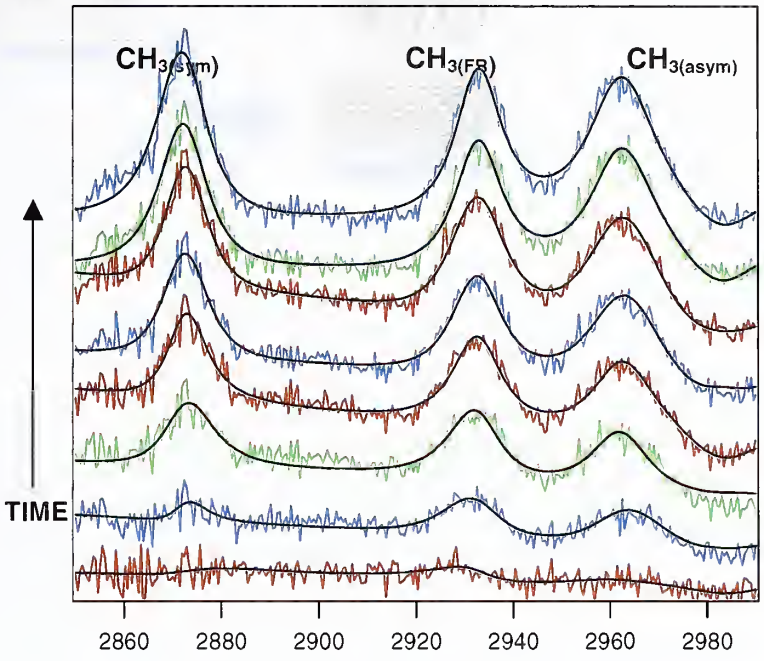


Sum Frequency Generation as an *In situ* Spectroscopic Probe of Hybrid Bilayer Formation

Vibrationally-Resonant Sum-Frequency Generation - a unique tool to study kinetics at liquid/solid Interfaces, providing real-time measurements of membrane formation from unilamellar vesicles

Hybrid bilayer membranes (HBM), in simplest form consisting of a phospholipid monolayer on an alkanethiol self-assembled monolayer (SAM) on gold, are promising matrices for new biomaterials. Since the mechanism of bilayer formation may affect the resulting composition of the HBM, an *in situ* spectroscopic method of following HBM formation and structure is highly desired. Sum frequency generation (SFG), a nonlinear optical vibrational spectroscopic technique, is among several methods being developed as *in situ* probes of HBMs. SFG offers powerful advantages due to its high surface selectivity, submonolayer sensitivity, and excellent spatial, spectral and temporal resolution. SFG is potentially able to give direct information about the structure, orientation, aggregation, and organization of surface-associated biomolecules.

Selected VR-SFG spectra recorded during the HBM formation



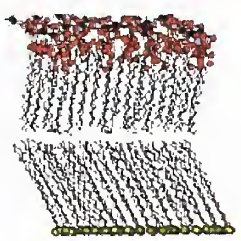
In SFG, two laser beams of different wavelengths, one visible (V) and one infrared (IR), are simultaneously reflected from an interface. Due to the nonlinear properties of the surface, a visible photon ω_V and an infrared photon ω_{IR} can interact to create a third photon with a frequency that is at the sum of the two photon frequencies, $\omega_{SF} = \omega_V + \omega_{IR}$. Thus, the broadband sum-frequency generation system (BBSFG) developed at NIST [Opt. Lett. 23, 1594 (1998)] is being utilized in these studies. In BBSFG, broad bandwidth IR is used so that an entire SFG spectrum is collected from every laser pulse, which allows rapid spectral acquisition. Vibrational spectra are routinely collected on the order of minutes, well within the time resolution needed to follow HBM formation. Since SFG band intensities may be proportional to the number of adsorbed molecules, the adsorption of phospholipids during the formation of an HBM can be followed *via* the growth of SFG bands over time.

Research promotes ability to:

- **Characterize the influence of both lipid chain structure and substrate functionalization on the kinetics of HBM formation**
- **Improved understanding of cell membrane dynamics**
- **Basis for improved designs for HBM-based sensors**

Supported Hybrid Bilayer

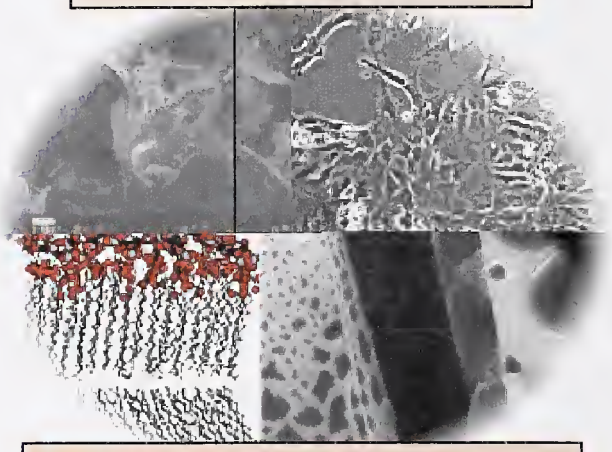
The top layer of phospholipid is associated through hydrophobic interactions with the bottom alkanethiol monolayer bound by sulfur to a gold substrate.



Biomaterials for Tissue Engineering: Incorporating Biological Functionality into Man-made Materials

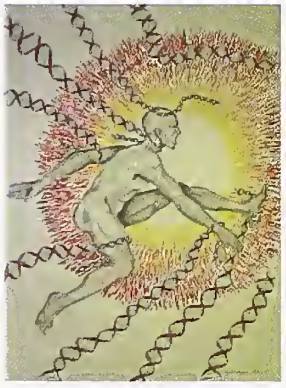
Biomimetic materials: Current research focuses on the synthesis, characterization, and fabrication of biomaterials; biomimetic membrane surfaces and devices, which will be designed to control, cell behavior and tissue development. A variety of signals can be conveyed to cells from a material, and both chemistry and mechanics of the material regulate signal transduction. Control of both bulk and surface chemistry/structure may be utilized to affect this regulation. These materials may be used as *in vitro* model systems to study basic biological questions, or as systems to regenerate lost or deficient tissue structure *in vivo*. NIST is developing an *in vitro* biomimetic enriched membrane construct to be used as adhesion, and incorporation of cell/polymer composites (grafts) with the neighboring host tissue. In addition, these *in vitro* model systems will be utilized as tools to access the mechanisms and the kinetics of molecular interactions between cell membrane receptor/effector molecules and the unique extracellular matrix components. Understanding the above criteria will help in modifying both the bulk and the surface of biomaterials to regulate biomolecular recognition and for designing micro and macro patterned biomaterials for targeted cell adhesion. These novel biomimetic materials may be re-engineered and designed to be utilized as tools that may serve as: scaffolds for cell co-culture transplantation, immuno-isolation, cell-response stimulants (e.g., electrically conducting polymers), carriers for tissue induction factors (e.g., bone morphogenic proteins), conduits and barriers for guided tissue regeneration and construction of gene delivery vehicles. These biomimetic materials, will be important tools for enhancing the understanding of the critical role of the micro-environment in the acceptance or rejection of implants, and for clarifying the cell-biomaterials interface and cell-cell adhesion mechanisms.

ESEM micrographs of MC3T3-E1 cells on HA/P(LAGA) biomaterial surfaces in culture



Self-assembled monolayers on gold provide a substrate to which cell membranes can reorganize to form cell membrane-containing hybrid bilayers.

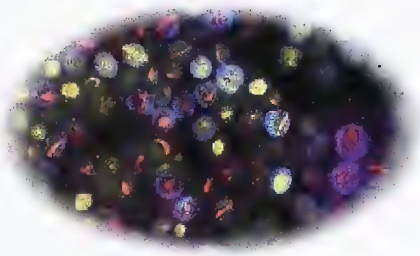
Standard Reference Materials to Support Biosensor Development



BioSpectroscopy - *developing the scientific basis for producing viable fluorescence intensity standards*

Spectroscopic and electrochemical instrumentation such as linear sweep voltammetry (LSV), surface enhanced Raman spectroscopy (SERS), electroreflectance spectroscopy (ER), and spectroellipsometry (SE) have been developed to characterize biomolecular processes such as electrical or optical energy transfer between redox or fluorophore centers and external surfaces. These techniques are being used to characterize electrode surfaces, to measure electron transfer in several redox proteins (e.g. putidaredoxin -- iron-sulfur redox center, azurin -- copper redox center, cytochrome c -- heme redox center), and to characterize the stability and quenching of model fluorophore-interface systems.

Commercial application of redox enzyme biotransformations is hampered by the lack of data and models for intra- and inter-protein electron transfer, and by lack of inexpensive and reliable sources of reducing power. The application of fluorescence-based assays in biotechnology for purposes of tracking cellular genetic and metabolic activity has increased dramatically, and further advances in the field are impeded by the absence of fluorescence intensity standards. Both knowledge and data are important in the design/development of biocatalysts and biosensors.



The figure, taken from the Web site of Molecular Probes, Inc, illustrates the use of two-color fluorophores to qualitatively assess different metabolic functions occurring simultaneously within Saccharomyces cerevisiae, an important industrial biocatalyst. The ability to use these measurements for quantitative descriptions of metabolism requires normalization of the fluorescence signals through use of intensity reference standards that do not exist on an absolute level at the present time.

New Healthcare Standards Enhance Quality of Patient Care

❖ Establishing Reference Systems for New Clinical Markers

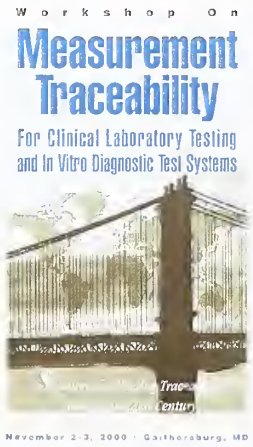
Troponin-I	Myocardial Infarction
Gylcated Hemo.	Diabetes Status
Homocysteine	Risk of Heart Disease
P_{53} DNA	Breast Cancer
TSH	Thyroid Function
Speciated Iron	Hemochromatosis, Anemia
Human Serum Alb.	Renal Failure
PSA	Prostate Cancer
Cadmium & Mercury	Toxic Metal Poisoning
Cortisol	Endocrine Function
Thyroxine	Thyroid Function

Measurement Challenges

- **High molecular mass proteins (>20,000 daltons)**
- **Heterogeneity of the protein**
- **Separation of different forms of the protein**
- **Serum matrix complex; analyte level low**
- **Stability of both matrix and analytes**
- **Standardization necessary before medical diagnostic benefit can be realized**

"Failure to use effective treatments . . . for acute myocardial infarction for all patients who could benefit from these interventions may lead to as many as 18,000 preventable deaths each year in the United States." *JAMA, 280, 1000, September 1998.*

Meeting Industry Needs in a Global Economy:


Workshop On
Measurement Traceability
For Clinical Laboratory Testing and In Vitro Diagnostic Test Systems
November 2-3, 2000 · Gaithersburg, MD

A Workshop on Measurement Traceability for Clinical Laboratory Testing and In Vitro Diagnostic Test Systems

One of the driving forces for this workshop is the proposed ISO standard for Calibration Traceability of *In Vitro* Diagnostic Medical Devices, which is being drafted in response to the European Union Directive. This Directive requires that all IVD assays be traceable to the highest available reference material or method.

Location: National Institute of Standards and Technology, Gaithersburg
Date: November 2-3, 2000.

Website: http://www.cstl.nist.gov/nist839/ivd.html

Threonine Deaminase (TD) X-ray Crystal Structure: A key metabolic enzyme for industrial applications

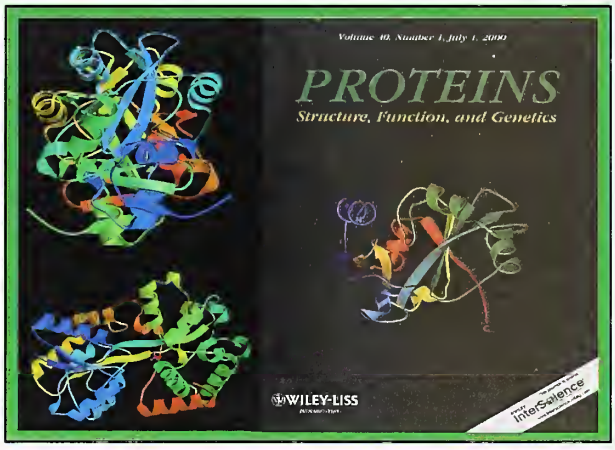
Polyhydroxybutyrate biodegradable plastics are derived from its enzymatic product alpha-ketobutyrate, and, because TD is present in bacteria and plants but not in humans or animals, specific inhibitors could provide improved methods of controlling bacteria or weeds. One of the first enzymes to be recognized as allosterically controlled, TD has been the subject of intensive study at NIST/CARB (Center for Advanced Research in Biotechnology) for several years.

Threonine deaminase is a large protein (2056 residues in the tetramer) that exemplifies current challenges in x-ray crystallographic structure determination. Several crystal forms diffracting to high resolution have been described. This project has provided an opportunity to test new techniques for measuring crystal growth and for structure elucidation that are under development. This research has led to a CRADA with BioSpace International Inc.(Rockville, MD) developing hardware for protein crystal growth. The 220-kDal TD structure has been reported at 2.8 Angstrom resolution and deposited in the **Protein Data Bank** under accession code 1TDJ.

PDB

NIST/CSTL Manages First NIH awarded Structural Genomics Program

The **structural genomics program** began in 1998, and was initiated to advance the understanding of the function of so-called "unknown proteins" that have been uncoded in fast-paced contemporary genomic research. In an innovative approach, scientists at NIST's CSTL, the University of Maryland Biotechnology Institute, and the Institute for Genomic Research are determining the 3-dimensional structures of these unknown proteins in genomic data in order to deduce the functions of the proteins on the molecular level, and eventually to extend this molecular information to the cellular and organism level. This approach has been coined **structural genomics**. While the goal of understanding protein function is the same, this approach differs conceptually from **functional genomics,** in which the actual function of proteins on genes is studied on a cellular level.



To date, the structural genomics team has expressed and purified 31 proteins of unknown function. Of these, 21 proteins have crystallized, 9 had diffraction-quality crystals, and 9 structures have been solved - 7 by x-ray crystallographic methods and 2 by NMR methods. This structural information will help elucidate interactions of proteins with each other, nucleic acids, carbohydrates, lipids and other biomolecules. It is clear that deciphering the function of these proteins is the next step in genomic research, advancing our understanding of the biochemical processes of the cell, and permitting the identification of new drug targets and the developments of new treatments for disease.

NIST partners:
- **The University of Maryland Biotechnology Institute**
  http://www.umbi.umd.edu/
- **The Institute for Genomic Research**
  http://www.tigr.org/

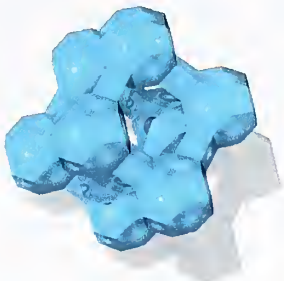
http://s2f.carb.nist.gov/
http://www.structuralgenomics.org/

Catalysis

"Those who develop new cost-effective catalysts and biocatalysts that improve the yields of products, cheapen or simplify processes, ... or reduce the amount of pollution produced during manufacturing processes will gain clear competitive strategies."

ATP White Paper

Zeolite Reference Materials: for benchmarking and assessing measurements, materials and instrument performance



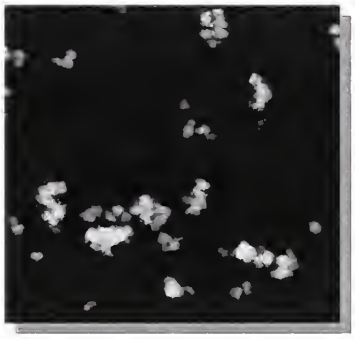
Crystalline Structure of Faujasite

With the reduction of Industrial R&D funding, industry became more dependent upon academia for materials research. Materials composition, based on performance, is increasingly challenged and disputed. The zeolite standards developed at NIST permit benchmarking.

Zeolite code names are generally based on crystal structures, but some of the more modern materials have names that reflect the companies that discovered and/or developed them. The NIST suite of materials was selected to provide a range of compositions in the more popular structures.

- **Three SRMs in production (SRMs 2850, 2851, 2852)**
  - FAU - Faujasite
  - LTA - Zeolite A (Linde Division, Union Carbide)
  - MFI - Zeolite Socony Mobil - 5
- **Eight RMs to follow (RM 8200 - 8207)**
  - BEA - Beta
  - FAU - Faujasite (2)
  - FER - Ferrierite
  - MFI - Zeolite Socony Mobil -5 (2)
  - MOR- Mordenite (2)

Scanning Transmission Electron Dark Field Micrograph SRM 2850- FAU



Materials Characterized for:

1. **Elemental composition**
2. **Particle size**
3. **Lattice parameters and phase purity**
4. **Catalytic properties**
5. **Micropore volume**

Industry Partners:
UOP, UCI DuPont, Air Products, Mobil, W.R. Grace-Davidson, PQ Corp., Tosoh

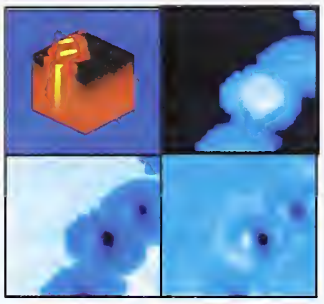
Near – Field Optical Microscopy for Artifact-free Topographies of Surface Structures

NIST/CSTL is developing data acquisition and analysis methodologies for near-field scanning optical microscopy (NSOM) that distinguish and minimize artifacts while providing factual NSOM images.

In NSOM, high spatial resolution is achieved by scanning a sub-wavelength aperture over the sample surface. Typically, the aperture is scanned while maintaining a constant gap (~ 3-5 nm) between the aperture and the sample producing a constant-gap mode (CGM) image. An NSOM based on CGM provides topographic and optical information. However, operating an NSOM in CGM on rough surfaces generates z-motion optical artifacts that arise from a change in optical intensity as the separation between the aperture and sample is varied. One method that eliminates z-motion artifacts is to acquire the data in constant-height mode (CHM) by scanning the aperture at a set height above the average surface plane. Direct acquisition of CHM images is hampered by a lack of suitable gap-maintaining technologies and a prior knowledge of sample topography.

Constant Gap Mode (CGM)

Constant Height Mode (CHM)



Top Left - Cube of NSOM data recorded in three spatial and one optical dimension

Images constructed from the (top right) topographic, (bottom left) CGM, and (bottom right) CHM

A new method for acquiring NSOM data allows for the construction of three types of images from one data set: topographic, CGM, and CHM. Instead of collecting optical data at a fixed aperture-sample gap at each XY position, optical data is collected along a controlled scan taken normal to the surface at each XY position. This produces cubes of data as shown in the top left quadrant of the figure.

The CGM image shows many of the features present in the topographic image. In the CHM image, the majority of the CGM features observed are no longer present, indicating that they resulted from z-motion artifacts. The prominent features observed for each particle in CHM image consist of a dark center spot surrounded by two lighter lobes. This is the factual NSOM image. Currently under development is an improved (reduced acquisition time) algorithm for the acquisition of artifact-free NSOM images as well as data analysis tools for evaluating CGM images for artifacts.

Applications

- **To assess local structure of catalytic sites**
- **Taggants for rapid screening**
- **High-speed optoelectronics to operate microprocessors at GHz speeds**

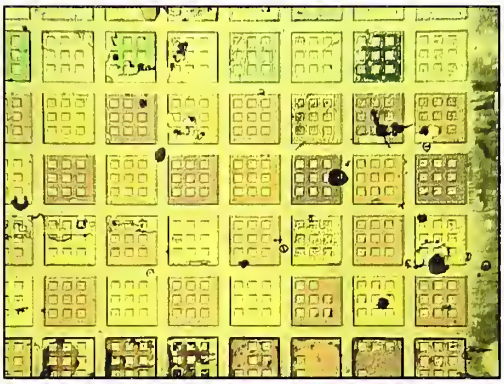
Combinatorial methodology is a set of tools and techniques to react various components in different combinations and then rapidly and automatically screen for desired properties. The approach uses a large number of carefully designed, multi-dimensional experiments performed on a miniaturized scale using automated instrumentation. Collections of materials called libraries are created in this way. Using this approach, new materials can be designed, synthesized and screened at an unprecedented rate. Although major technical challenges exist, the combinatorial approach to material discovery has already revolutionized R&D in the pharmaceutical industry. The potential impact in the broader chemical and materials industry is becoming apparent, and will likely drive a significant change in the R&D approach in these fields. The chemicals and materials science communities are now considering the possible ways combinatorial methodologies can be used to accelerate the processes by which knowledge is discovered and products and processes developed to meet the advanced materials needs of the 21st century. *(Combinatorial Methods Roadmapping Workshop for Technology Vision 2020)*

Combinatorial Catalysis:

"The train is leaving the station. You are either on board, or will be left behind."
Richard Gross, VP for R&D, Dow Chemical

In response to this emerging need, NIST is currently developing methods to evaluate libraries of catalytic materials.

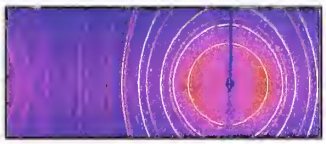
Library Array of Dielectric Materials



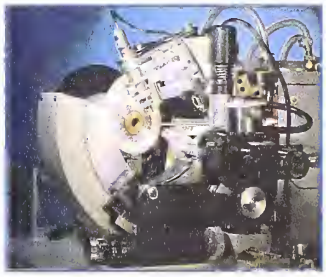
- **Anticipated impact of high throughput experimentation on materials research is large**
- **Comprehensive rapid screening of materials for new, improved properties**
- **Components needed**
  - **Libraries**
  - **High-Throughput Assays**
  - **Informatics**
- **Successes Reported**
  - **Phosphors, magnetoresistive materials, high-temperature superconductors, dielectrics, semiconductors, catalysts, zeolite**

In a multi-laboratory effort including CSTL, BFRL, ITL, and MSEL, NIST is developing **micro-X-ray diffraction** techniques for phase identification and phase evolution studies.

X-Ray microdiffractrometry is nondestructive and identifies local phase and orientation as well as crystalline structure.



Diffraction Analysis

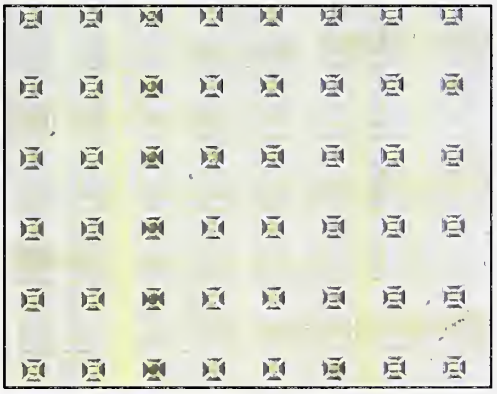


Micro-FT-Raman techniques are being developed by NIST's CSTL, EEEL, and Physics Laboratories for residual stress measurements in compositionally varying polycrystalline materials. This method is nondestructive and provides rapid throughput, and enables the evaluation of stress-enduced peak shifts.

Gas-Sensing with Microhotplate Sensor Arrays

Increasing global competition has placed new demands on the chemical process industry for more efficient use of materials, better process reproducibility, and environmental safety. Meeting these demands requires a low-cost technology for the measurement of gas species, which can provide immediate, on-site analysis for the detection of reaction products, exhaust gases, leaks, etc. Gas-phase measurements are also needed for applications ranging from environmental monitoring at hazardous waste sites to chemical agent detection.

Advances in microfabrication technology now make possible miniaturization of conventional conductometric low-cost metal oxide sensors into a planar array form. At NIST, a sensor array platform has been developed which uses a "microhotplate" as the generic device structure. The microhotplate has three functional layers: a heater, a thermometer/heat distribution plate, and electrical contacts for monitoring the conductivity of sensing films. NIST holds three patents on this technology. There are three key components to the microsensor research program: advancing sensor materials, understanding transducing mechanisms, and developing new methods for sensor operation and signal analysis. Catalyst-doped metal oxide materials are used for sensing films and evaluated on the basis of sensitivity, selectivity, and stability. The dominant sensing mechanisms under investigation include catalyzed reactions, adsorption/desorption, grain boundary diffusion, and electronic effects related to surface states created by chemisorbed species. Surface analytical techniques combined with electrical measurements are used to address these issues. New sensing modes are possible that use the ability of these devices to be heated and cooled in milliseconds over a large operating temperature range (>500 °C). In temperature programmed sensing, the sensor is subjected to a repeating pattern of temperature pulses. Effects that produce a response signal are based on thermally-activated processes, such as adsorption, reaction, and desorption. The sensor generates repetitive response signatures that are characteristic of adsorbed species/sensing material combinations. Neural network and chemometric-based approaches to this problem are being used to optimize the generation of patterns and to analyze signals during sensing.

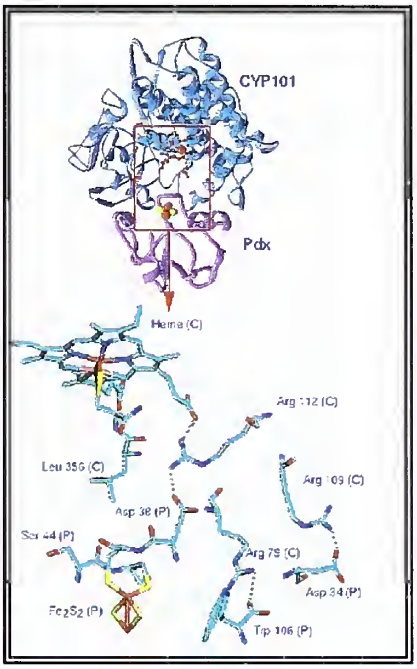


A study comparing catalysts composed of platinum (Pt), palladium (Pd), and copper (Cu) of different thicknesses showed large enhancements to the sensitivity. Films with 5 nm Pt produced the greatest sensitivity to 50 µg/g methanol in air. This work utilizes newly fabricated large arrays with 48 sensing elements for combinatorial experiments on sensing materials and large-area structures for studies of sensing mechanisms using mass spectrometry combined with electrical sensing.

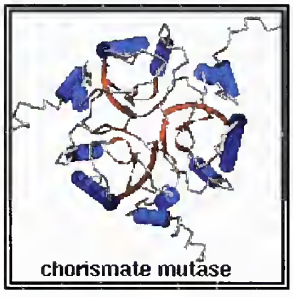
Biocatalysis

Many new metabolic pathways are being discovered and promoted for use in making chemicals from renewable resources (e.g., glucose from crop spoilage). The separate enzymatic steps in these pathways are not well characterized, as compared to the wealth of knowledge about pathways in mammalian cell physiology. Information such as biocatalytic rates, enzyme structure/function relationships, and genetic and allosteric control of reactant specificity is needed for successful industrial bioprocess development to occur.

NIST is using molecular biology to engineer and produce proteins whose coordinated activity is then characterized and modeled by various measurement and computational chemistry techniques. Site-directed mutagenesis, NMR spectroscopy, and X-ray crystallography/diffraction are used to determine and analyze molecular structure, while various molecular modeling techniques are used to interpret function.



One biocatalytic system under study is cytochrome P450 (CYP101) and its electron transfer partners, putidaredoxin (Pdx) and Pdx reductase. Interactions responsible for binding and electron transfer pathways between putidaredoxin (Pdx), a protein that shuttles electrons in cytochrome P450 systems, and its redox partners are under investigation. A combination of experimental and computational chemistry techniques has allowed us to identify a triad of residues in Pdx and CYP101 that are responsible for most of the electrostatic interactions between these two proteins. Of those residues, we have identified one in each protein that is directly responsible for electron transfer. Arg 112 (CYP101) and Asp 38 (Pdx) act as 'cables' for the electron transfer event; if mutated, the overall activity of the system decreases to very low levels. These results highlight the usefulness of theory/experiment interactions. Additional insight into this system comes from NMR spectroscopy. Techniques utilizing multidimensional proton and nitrogen-15 spectra have provided measurements of several key molecular parameters. Direct measurement of nitrogen-15 spin-lattice relaxation times has enabled us to deduce inter-atomic distances in the paramagnetic region near Pdx's iron-sulfur cluster, while indirect measurements of T1, T2 and NOE values have given information on the dynamic motions of this protein.



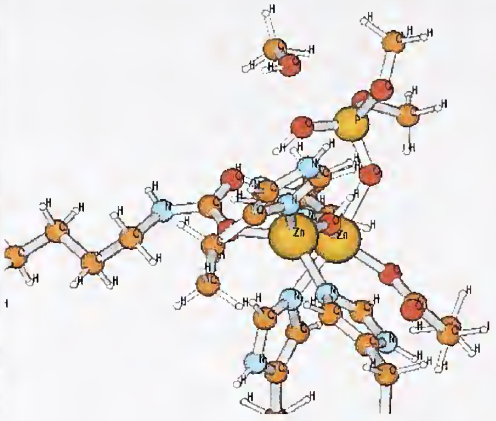
The biosynthetic pathway leading from glucose to chorismate and its aromatic derivatives has major industrial potential and is another system under study. This metabolic pathway is being developed as a model system for bioprocess measurement and modeling technology.

Through collaborations with industry and government laboratories, enzymology and structural investigations of several key components that may be amenable to engineering for improved pathway throughput have been initiated. Some chorismate pathway genes have been cloned, purified and mutated to test biological function. The structure of chorismate lyase has been solved at 1 Angstrom resolution, and product inhibition has been quantified. Equilibrium and calorimetric measurements, as well as modeling, has been used to characterize the thermodynamics of enzyme-catalyzed reactions. In addition the NIST Enzyme Catalyzed Reaction Thermodynamics Standard Reference Database has been created.

http://www.cstl.nist.gov/div831/

Modeling Molecular Recognition – algorithms to compute enzyme activity

The noncovalent association of molecules in solution is of fundamental importance in biology and chemistry. Software for predicting what molecules will bind each other, and how tightly they will bind, is needed by industry in order to avoid the need for time-consuming and expensive binding measurements. Such software will be useful for designing molecules targeted to bind specific other molecules. Examples are drug molecules that work by binding enzyme active sites, and smaller host molecules that can be used for chemical separations. However, predicting binding affinities with sufficient accuracy and speed is difficult because of the complexity of the systems.



Active site of phosphotriesterase, all-electron complex with transition state for hydrolysis of trimethylphosphate.

The **NIST/CSTL approach** has two main elements. The first is the use of simplified—and therefore computationally fast—treatments of the solvent that nonetheless capture much of the relevant physical chemistry. The generalized Born/Surface Area (GB/SA) solvation model is bound to be fast and can readily be corrected toward the results of more rigorous models. The second element of the approach is the use of a novel "mining minima" algorithm. This algorithm rapidly identifies the most stable conformations of a small-molecule system, and then computes the contributions of these conformations to the overall free energy. It combines an efficient energy-optimization method with careful treatment of the underlying statistical thermodynamics.

Strong agreement with experiment for a range of small-molecule systems has been found. The most recent case studies involve the association of adenine with a series of seven synthetic adenine receptors, and the association of cyclic urea inhibitors with HIV-1 protease. The present methodology also has proven useful for elucidating the mechanisms by which oxygenated aromatic compounds interact with an ester polymer sorbent used in chemical separations.

Future plans include further enhancements of the implicit solvation model, and generalization of the mining minima algorithm to make it applicable to molecules with flexible rings and restrained loops.

Green Chemistry

A Business View of Sustainable Development

"The green economies and lifestyles of the twenty-first century may be *conceptualized by environmental thinkers,* but they can only be *actualized by industrial corporations*. Industry has a next-century vision of integrated environmenal performance. Not every company is there yet, but most are trying. Those that aren't trying won't be a problem long-term, simply because they won't be around long-term. This is the new competitive reality".

Edgar Woolard, ex-CEO DuPont

Petroleum or Corn Feedstock??

The "triple bottom line" is a rhetorical device used to signify the beneficiaries of "Green Chemistry." These beneficiaries are society, industry (the economy), and the environment. Society depends on industry to provide products to improve the quality of life - and industry depends on the global ecosystem, whose health represents the ultimate bottom line. "Green" Biotechnology offers wide possibilities to impact the triple bottom line. While the cost of oil -and America's dependence on foreign suppliers - has risen, U.S. Industry has invested in the triple bottom line by developing uses for cheap and renewable bio-matter through biotechnology. Large capital expenditures are necessary for commercialization, however, and some barriers to this commercialization exist that NIST can address.

For example, a traditional process to manufacture the polymer Polypropylene Terephthalate (PPT) [a.k.a. Polytrimethylene Terephthalate, PTT] uses high-purity 1,3-propanediol (PDO). This PDO is expensive and manufactured from acrolein, a caustic and toxic chemical derived from (non-renewable) petroleum. Industry watchers anticipate that PPT will supplant Polyethylene Terephthalate (Polyester, PET, ***a multi-billion dollar global industry***) in importance, and the various domestic and foreign manufacturers of PPT are strategically developing lower-cost PDO technologies. In this regard, DuPont teamed with the biotechnology firm Genecor to genetically design a yeast that could convert glucose (in corn syrup) to PDO. DuPont came to NIST with a problem: since PDO from glucose was chemically identical to PDO from acrolein, no "substance of matter" patent was possible to protect their process from competitors. In other words, their investment was at-risk, and future investments and decisions in converting PET plants to produce PPT were problematic. Measurements were needed that could distinguish PPT made by their unique process; measurements of the highest traceability which could be used to legally defend their product and process.

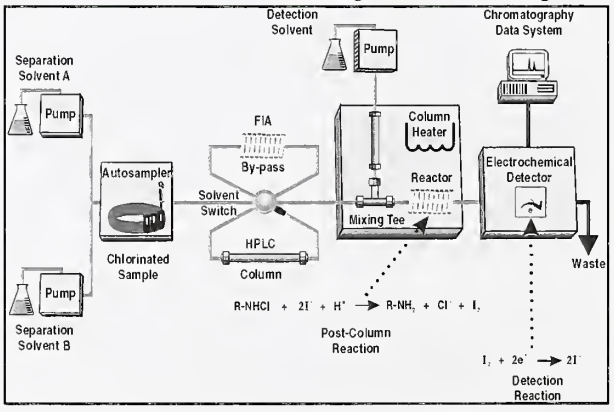
NIST/CSTL's solution was based on their competency in advanced isotope metrology. Since carbon derived from corn is isotopically distinct from that derived from petroleum, measurements of carbon-13 and carbon-14 in PPT and PDO would enable differentiation between the possible origins of these materials. An isotopic "fingerprint" could be used to unambiguously identify the DuPont PPT and help protect their investment. The challenge was to design isotopic measurements of the highest possible traceability for the purpose.

Measurements of Chlorination Products in Waste Water and Drinking Water

Over 40 billion gallons of sewage wastewater is discharged into the environment by municipal treatment facilities in a single day in the U.S. The primary means of protecting human health and the environment from the toxic effects of pathogenic bacteria and viruses is to disinfect drinking and waste-water with chlorine (either as chlorine gas or as hypochlorite solutions). The efficacy of the disinfection process and treatments is highly dependent on the nitrogen-bearing components in the water. In particular, inorganic ammonia and "organic" amines provide a significant "chlorine demand," lowering the effectiveness of the chlorine disinfection. When the chorine reacts with the amine compounds, N-chloramines are formed. These compounds are important as they may provide chronic toxicity to aquatic organisms (wastewater) and are the precursors of carcinogenic trihalomethanes (THMs) such as chloroform (drinking water).

Although it has been well known since the 1970's that chloramines are formed in drinking and wastewater treatment processing, their reliable measurement remains problematic. Generally, a titrimetric or colorimetric procedure is used to determine "total residual chlorine." However, neither technique can reliably distinguish between the inorganic and organic amines, which vary greatly in their toxicity. In addition, current techniques cannot accurately measure chloramines below the part-per-million range (ppm). Permits for wastewater discharge and water treatment generally require total residual chlorine (TRC) to be below 0.1 ppm or 2 ppm, respectively. EPA has established a "Criteria" for wastewater discharge that is 11 ppb (0.011 ppm) as a goal for sewage wastewater discharge, so techniques are needed that can make reliable measurements at that level.

NIST/CSTL has been developing and is currently refining an analytical method that can measure chloramines in a manner that discriminates between the inorganic and organic chloramines that are formed in water chlorination. The new technique offers the analyst the choice between a TRC measurement by flow injection analysis or a determination of individual organic chloramines based on a reverse-phase liquid chromatography separation. The active chlorine species are measured by reaction with iodide to form iodine, which is detected electrochemically. Our goal with the measurement system is to obtain a stoichiometric response for all active chlorine species so that TRC may be compared to its individual chloramine components. This will allow an understanding of the relative role of the organic amines in chlorination processes.

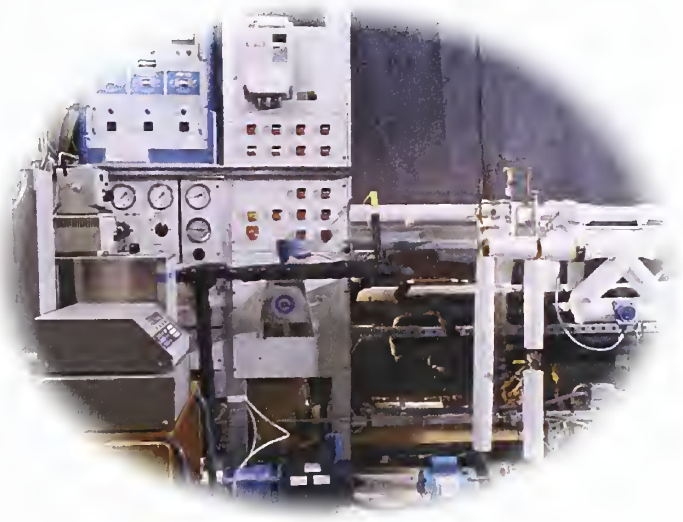


In addition, measuring and understanding the contribution of organic chloramines to TRC will help water process engineers minimize the initial dosage of disinfecting chlorine, and the final dosing with dechlorination agent, which will lower operating costs while minimizing the environmental impact.

NIST/CSTL Provides Experimental Data to Support CO_2-based Refrigeration

Worldwide efforts to protect the ozone layer have led to a search for replacement fluids for chlorofluorocarbon-based refrigeration cycles. Although one potential replacement, hydrofluorocarbons (HFCs), does not damage the ozone layer, they contribute to another environmental problem, global warming. In 1993, the late Gustav Lorentzen of Norway proposed a return to the use of carbon dioxide in refrigeration and heat pump cycles. On a mass-based comparison, carbon dioxide has 3100 times less Global Warming Potential than HFC134a. It is also inexpensive, non-toxic, and has no other known environmental effects. However, the fluid properties of carbon dioxide are different from existing refrigerants, and they require re-design of the machines used in the cycles. In order for CO_2 to be a suitable replacement fluid, machines using it must perform comparably, be economically feasible, and be safe.

Refrigeration cycles using carbon dioxide will need to operate in the supercritical regime during heat rejection to the environment. Because the properties of a fluid vary considerably near the critical point with small changes in temperature or pressure, flow behavior and the transport of heat potentially are very different in this regime and must be studied carefully to develop accurate predictive methods for process design. Little data exists on which to base these design methods. **NIST/CSTL researchers** have measured the thermal performance of a type of process heat exchanger that has been proposed for a carbon dioxide-based alternative refrigeration cycle. The system tested was prototypical of the widely used shell-in-tube heat exchanger. Specifically, it was a horizontal tube, 2.74 m long by 10.9 mm ID, with cold water flowing countercurrent on the outside of the tube.



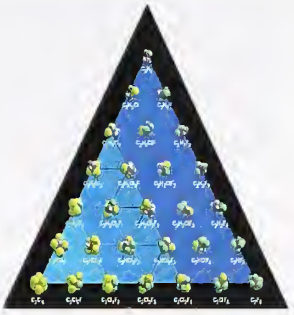
Measurements were made at operating pressures from 7.4 MPa to 13.0 MPa, fluid flow rates from 1.0 kg/min to 5.0 kg/min, cooling rates from 1780 W to 6220 W, inlet temperatures from 31.6 °C to 88.6 °C, and outlet temperatures from 23.2 °C to 55.5 °C. The results showed significant improvement in thermal performance for the supercritical fluid when compared to a conventional fluid. The present results also showed that existing engineering correlations could predict the measurements when the operating temperatures were above the critical, but not when they were below the critical.

This same tube has been tested under conditions where the carbon dioxide is heated instead of being cooled. This configuration will be important in processes such as supercritical water oxidation, a method proposed for neutralizing aqueous chemical wastes. For supercritical heating, high fluid flow and low heating cause the thermal performance to exceed that of a conventional fluid, whereas low fluid flow and high heating produce poorer performance than for a conventional fluid. These experimental data will be valuable in developing predictive methods for design of heat exchangers in alternative refrigeration cycles or other modern technologies utilizing supercritical fluids.

Tools for Evaluating Environmental Impact

NIST Standard Reference Database 23

NIST Thermodynamic and Transport Properties of Refrigerants and Refrigerant Mixtures Database:



In order to meet the phase out schedule of the Montreal Protocol (1987), it was necessary to develop new types of refrigerants that would retain the desirable physical properties of CFCs but would pose little or no threat to the ozone layer. With this time-table as an incentive to develop new alternatives, NIST/CSTL engaged in research to allow industry to make the switich to alternative refrigerants in a timely and economic fashion. This research was built on core competencies already in place within CSTL.

NIST began by identifying the basic requirements for new refrigerants according to the new rules, and then began research on the determination of the physical properties of such candidate alternatives. The results of these research efforts were made available to industry. NIST's most effective form of information dissemination has been the REFPROP program, a computer package that is available throught NIST's Standard Reference Data Program. First released in 1987, this database is used by both manufacturers and users of alternative refrigerants. A key benefit of this program is the ability to model the behavior of refrigerant mixtures.

NISTDATA

In a formal economic impact study of 1998, a conservative estimate of the internal rate of return for this program was calculated to be 433%.

Latest release: Version 6.0 is a complete revision of this database and includes 33 pure fluids and mixtures with up to 5 components:

- The environmentally acceptable HFCs, including R23, R32, R125, R134a, R143a, and R245fa.
- The HCFCs including R22, R123, R124, R141b, R142b.
- The traditional CFCs, including R11, R12, R13, R113, R114, and R115.
- The "natural" refrigerants ammonia, carbon dioxide, propane, isobutane, and 3 other hydrocarbons.

It contains the most accurate pure-fluid equations of state currently available:

- High-accuracy MBWR equations of state for 10 fluids, including the international standard EOS for R123.
- High-accuracy Helmholtz energy equations of state (new t o Version 6.0) for 8 fluids, including international standard equations for R134a and R32 and equations from the literature for R22, ammonia and others.
- The Bender equation of state for several of the "older" refrigerants, including R13, R14, R114, and RC318.
- An extended corresponding states model for fluids with limited data.

Mixture thermodynamic properties:

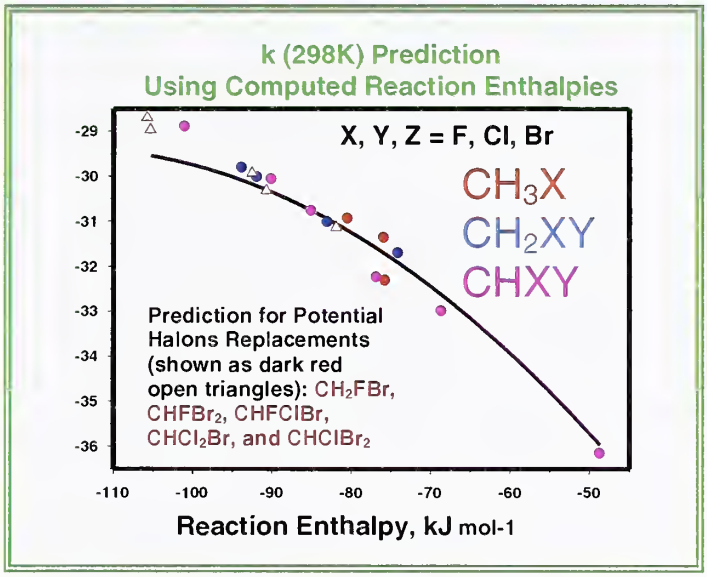
Mixture properties are calculated with a new Helmholtz energy model.
Experimentally based values of the mixture parameters in this model are available for 75 mixtures.

Surface tension of pure fluids and mixtures (new to Version 6.0)

Computational Chemistry

Development of a Computational Chemistry Screening Tool for the Prediction of Environmental Properties of Halogenated Organics

NIST/CSTL has developed a screening tool, based on quantum mechanics, for the prediction of the environmental impact of new classes of halogenated compounds. Experimental studies demonstrated that the reactivity of the hydroxyl radical toward halogenated organic compounds is not adequately correlated by simple structure-activity relationships. This was particularly evident when an ether linkage was introduced, where even the order of reactivity could not be predicted. This implied that it would be necessary to measure rate constants for a large number of members of any new class of reactants in order to predict the environmental impact of these possible new solvents, refrigerants, or fire suppressants. It was clear that a new approach was needed.



The NIST/CSTL strategy is: (i) to find the minimum level of *ab initio* molecular orbital theory suitable for predicting the reactivity of a set of halocarbons whose kinetics are well known, and (ii) to apply this level of theory for the prediction of the reactivity of new species. Part (i) has been done on a series of 13 halomethanes. For these compounds, the aim was to describe the reaction enthalpy, the temperature dependence of the rate constant, and to gain insight into the reactivity trends along the series of reactions OH + CHXYZ $\rightarrow$ H_2O + CXYZ (X, Y, Z = H, F, Cl, or Br). A comparison of the kinetic parameters estimated by these calculations with those derived experimentally, shows very good agreement. Step (ii) in this process involved the extension of these calculations to a series of bromine-containing halomethanes for which experimental data are not available: CH_2FBr, $CHFBr_2$, $CHFClBr$, $CHCl_2Br$, and $CHClBr_2$. This has been done both by the use of direct *ab initio* calculations employing transition-state theory and with an Evans-Polanyi's type relationship by utilizing the computed reaction enthalpies.

Tools for Monitoring Impact:

New Standard Reference Material for Air-borne Particulate Concentrations *(SRM 2784 Urban Dust On Quartz Filters)*

- ***Clean Air Act of 1997 reduced the requirement for monitoring particles from PM_{10} to $PM_{2.5}$***
- ***Regulations will require new standards for use in thermal-based analytical methods***
- ***New quartz filter packs have improved particle size segregation and more uniform spatial distribution***
- ***2240 filters will be produced and each standard will be gravimetrically verified for amount of total particulate***

Targeted for Chemical Characterization

- **Total organic carbon, carbon comp., total extractable mass**

–PAHs, PCB congeners, pesticides, inorganics

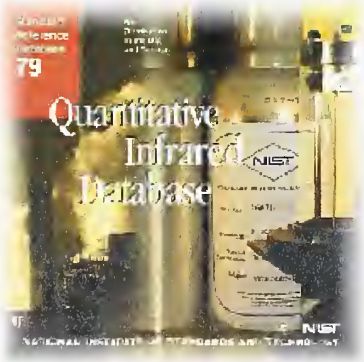
Standard Gas Mixtures for the Calibration of Automobile Emissions Monitoring Instrumentation

The 1970 "Clean Air Act" stipulated maximum allowable concentrations of specified pollutants that could be emitted from sources and maximum allowable concentrations of pollutants that could be present in the air. To determine compliance with the provisions of the Act, emissions of pollutants had to be monitored. To perform such monitoring with consistent accuracy, the Environmental Protection Agency (EPA) developed regulations that required the measurement systems used to be calibrated with standards from NIST or standards traceable to NIST. In response, NIST provided Standard Reference Materials (SRMs) for a range of gas mixtures.

The 1990 amendments to the Clean Air Act required considerably more pollutant monitoring, which, in turn, required a significant increase in the amount of calibration gases needed. The expanded need for traceability to NIST could not be met solely with the existing Gas Mixture SRM Program. That is, the market for compliance with EPA air quality regulations became too large for NIST to efficiently serve directly with primary standards (SRMs). In response, EPA issued new rules specifying how specialty gas companies (SGCs) could produce "EPA protocol gases" that could be used in place of SRMs to perform calibrations on the measurement systems used for air pollution monitoring. These rules stipulated that EPA protocol gas mixtures be developed based on analysis traceable to NIST. NIST then established a new program called the **N**IST **T**raceable **R**eference **M**aterial (NTRM) Program. Mixtures produced under this program provide the same traceability as SRMs. With the support of this new infrastructure, SGCs use a gas mixture NTRM to produce an EPA protocol gas that can be used in the field to calibrate instruments. These secondary reference materials have resulted in a great increase in the range and number of standards available to end-users. In general, secondary standards can be acquired faster and at lower cost.

Secondary standards have a mixed history of effectiveness. In the past, commercial suppliers of these standards have claimed traceability, but such claims were ill-defined and not recognized by NIST. In contrast, an NTRM is designed to have a well-defined traceability linkage to existing NIST standards for chemical measurements. This traceability linkage is established *via* criteria and protocols defined by NIST and tailored to meet the needs of the metrological community to be served. NIST/CSTL has worked closely with the 10 SGCs since 1993. To date, this collaboration had produced more than 367 batches of NTRMs representing approximately 8,500 gas standards. These gas standards are used by the SGCs to produce EPA protocol gas standards. The number of protocol gas standards produced from these NTRMs is approximately 500,000 with a market value of approximately $110,000,000.

FTIR Database - NIST SRD 79



Features:

- **Spectra for 31 of the most critical HAP compounds for remote sensing applications**
- **Available on CD in JCAMP-DX format with internet updates**
- **Data at several resolutions and apodization functions**
- **Digital signature to ensure file integrity**
- **Traceable to NIST primary gas standards**

Future Plans: **Interactive, web-based FTIR calibration**

Nanotechnology

"If I were asked for an area of science and engineering that will most likely produce a breakthrough of tomorrow, I would point to nanoscale science and engineering."

Neal Lane, Assistant to the President for Science and Technology

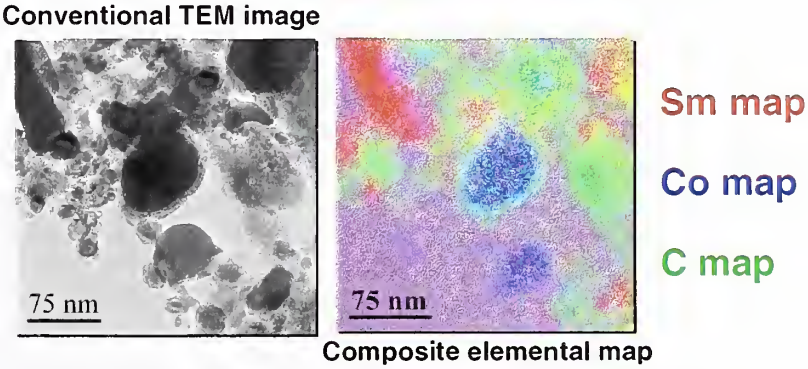
Nanoscale Chemical Characterization

The need for improved spatial resolution currently limits the ability of industry to answer key questions regarding the chemical composition of surfaces and interfaces. Needs range from improved chemical and structural diagnostics to phase identification and trace compositional analysis. In addition to meeting current industry needs in these areas, there is a continuing demand for new measurement methods to be developed that will be positioned to meet emerging measurement challenges. ***NIST/CSTL develops measurement tools*** that enable chemical characterization of elements, isotopes and molecules, at the millimeter to nanometer spatial scales with major, minor, and trace concentrations. These tools are developed such that the "microspatial" relationships can be correlated with specific macroscopic properties.

Chemical Characterization of Magnetic Materials at High Spatial Resolution

NIST is adapting nanoscale chemical characterization techniques in the analytical electron microscope (AEM) to materials challenges presented by advanced magnetic nanocomposite samples. Advances in magnetic materials research rely increasingly on information about chemical distributions at near-atomic dimensions. Sometimes this information concerns elemental distributions in artificial heterostructures, such as the multilayers in a spin valve. In other cases, information is needed about chemical or structural gradients that occur naturally during materials processing, such as recrystalliztion or segregation in an amorphous magnetic metal upon annealing. Several AEM-based nanoscale characterization techniques can be applied to these analysis problems, including convergent beam electron diffraction (CBED), energy-dispersive x-ray spectroscopy (EDS), and electron energy-loss spectroscopy (EELS). CSTL has been applying these tools to magnetic nanocomposites and investigating next-generation techniques such as electron spectroscopic imaging (ESI), including energy-filtered transmission electron microscopy (EFTEM) and spectrum imaging.

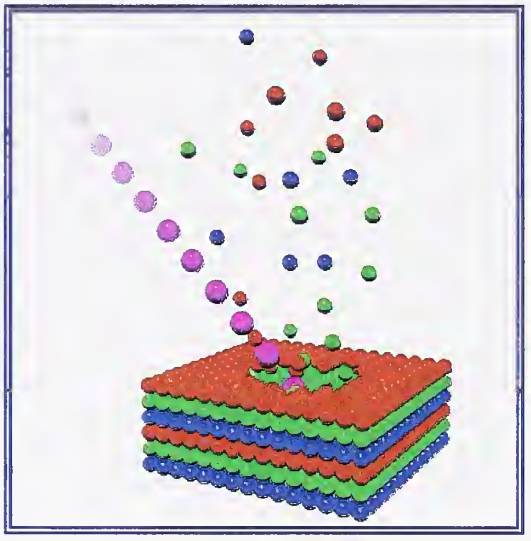
The AEM is capable of both imaging and chemical analysis with very high spatial resolution. In this case, an intermediate-voltage transmission electron microscope scanning transmission electron microscope (TEM/STEM) is used in TEM mode to image samples with a point-to-point resolution better than 0.2 nm, and is used in STEM mode to interrogate the sample with a finely focused probe approximately 1 nm in diameter. Conventional electron beam microanalysis is made possible by an EDS detector and an EELS spectrometer. Powerful new techniques have also been enabled by the addition of an imaging energy filter and a hyperspectral data acquisition system, designed to acquire EDS and EELS spectra simultaneously at each point of a 2-dimensional field of interest. Using the imaging energy filter, a series of energy-selected images acquired above and below a core-loss ionization edge can be combined to produce an elemental map of the sample, providing important clues to the variations in magnetic properties at very fine length scales.

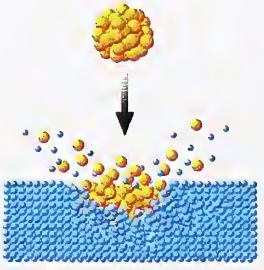


Multiple-energy-window maps can also be adapted to study changes in valence state of transition metal ions (e.g. Mn^{3+} vs. Mn^{4+}) in metals and magnetic oxides. Using hyperspectral data acquisition techniques and a scanned fine electron probe, both an EDS and an EELS spectrum can be associated with each pixel in a 1-dimensional profile or a 2-dimensional map. This "data cube" can then be processed offline to extract information such as compositional maps or valence state maps. The novel techniques described above were applied to magnetic nanocomposite powders and magnetic heterostructures. Sm-Co-C nanocomposites produced in an RF plasma torch from metal powder precursors and acetylene gas were mapped using EELS and energy-filtered imaging.

Cluster Secondary Ion Mass Spectrometry - Improved Depth Profiling for Thin-film Characterization

CSTL researchers are using secondary ion mass spectrometry (SIMS) to evaluate new approaches for analyzing organic and semiconductor surfaces by bombardment with energetic polyatomic (or cluster) primary ion beams. In this novel approach, the conventional SIMS *atomic* ion beam is replaced with a focused *polyatomic* ion beam that is used to bombard the surface of a material. The motivation for bombarding with polyatomic ions is based on two considerations. When a polyatomic ion collides with a surface, it dissociates into its constituent atoms, each atom retaining a fraction of the initial energy of the cluster. Since the depth resolution of most surface analysis techniques based on ion beam sputtering is directly related to the energy of the primary projectile, the use of polyatomic ions offers a method for obtaining ultra-high resolution depth profiles. In addition, as a result of its low penetration depth, most of the energy of a polyatomic projectile is deposited very close to the sample surface that may result in large enhancements in the number of ions or molecules desorbed from the surface, thus improving sensitivity. To explore these effects, a new type of ion source has been developed in collaboration with Peabody Scientific, Inc. of Peabody, MA. This ion source is used for generating beams of sulfur pentafluoride, SF_5^+. The CSTL team demonstrated that the polyatomic ion offers significant improvements in depth resolution for semiconductor and metal thin film analyses. For organic surfaces, characteristic molecular ion signals were enhanced by two to three orders of magnitude. Even more interesting was the unexpected observation that intact, characteristic parent molecular ions can be detected while sputter-depth-profiling through organic thin films and polymers.



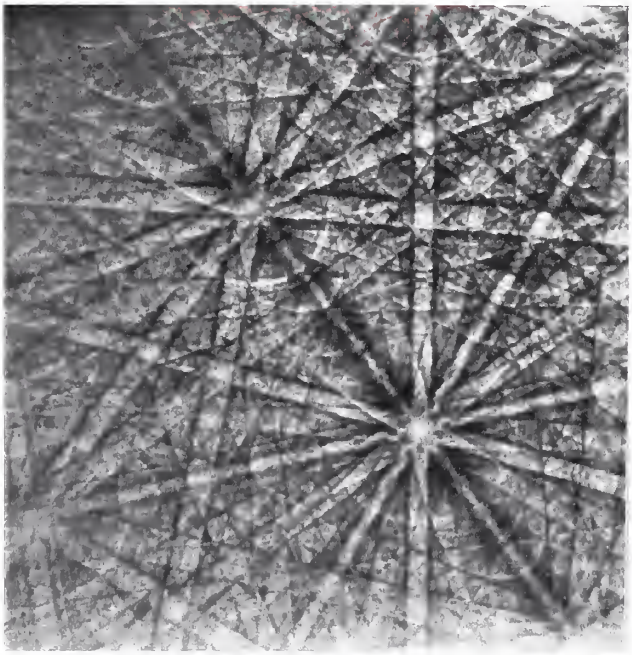


Phase Identification of Individual Crystalline Particles by Electron Backscatter Diffraction (EBSD)

NIST/CSTL researchers are developing a novel approach to the identification of the crystalline phase of individual micrometer and submicrometer particles in the electron microscope based on the analysis of electron backscatter diffraction patterns.

The effects of particle geometry and size often limit the accuracy and precision of the quantitative electron probe analysis of individual particles by x-ray emission. Typical uncertainties for particle elemental analyses are on the order of ± 10% relative at best which often makes the identification of the chemical phase of the particles difficult if not impossible.

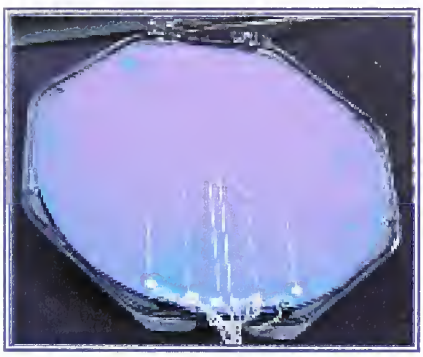
Phase Identification
Plattnerite, PbO_2
JCPDS #41 - 1492



Recently an EBSD Phase ID system has been commercially developed that enables the rapid identification of the crystallographic phase of unknowns in the scanning electron microscope. In this investigation, we looked at the application of the EBSD Phase ID system to the phase identification of individual micrometer and submicrometer particles rather than the conventional EBSD samples that consist of bulk samples with flat polished surfaces. Unlike conventional samples, the phase identification of individual particles may be complicated by several factors related to particle geometry and size. These factors include: difficulty in obtaining flat-field reference images for individual particles, effects of particle mass/size on EBSD image quality, pattern interference from nearby particles or substrates, and the effects of particle composition on EBSD image quality.

Nanoscale Fabrication

RTP Calibration for improved surface temperature measurements of in semiconductor manufacturing



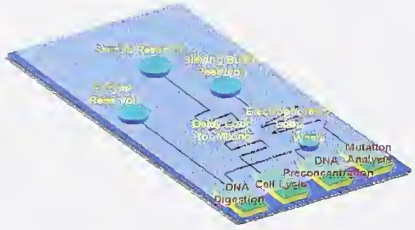
The semiconductor manufacturing industry needs higher accuracy than currently available in measuring the temperature of silicon wafers during processing to achieve goals in product quality and device performance. Consequently, the industry roadmap now requires an uncertainty of ≤ 2 °C at 1000 °C for RTP for the next generation of wafer patterning. Radiation thermometers are used in RTP but the uncertainty in measurements made with them is unacceptably large when the thermometers are calibrated against blackbodies. We are investigating the calibration of light-pipe radiation thermometers (LPRTs) using Si wafers instrumented with combinations of stable thin-film and Pt/Pd wire thermocouples (TCs). The thin-film TCs minimize errors from heat transfer that would be present for other types of temperature sensors. We have used our TC-instrumented calibration wafers in the NIST RTP tool for calibrating radiometers up to 900 °C.

Using this technique, the combined uncertainty was reduced to about 2 °C. This patented NIST process for attaching thin-film thermocouples to wafers gives improved surface temperature measurements (± 0.3 °C at 1000 °C). As a step in transferring our technology to the commercial sector, we have designed, fabricated, tested and delivered TC-instrumented calibration wafers to SEMATECH for their evaluation in their RTP tool.

Microfluidics: High-speed chemical analysis in miniaturized devices

"The Worldwide market for various analytical instruments ...is about $16 billion a year, and ... a large portion of it can be miniaturized. We expect a tenfold increase in the quality and amount of information generated as a result of this technology [microfluidics]"

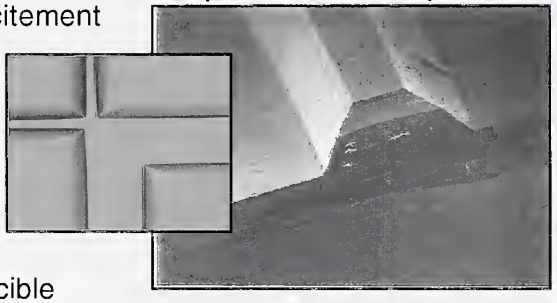
Rick Kniss, Agilent as quoted in Fortune Magazine



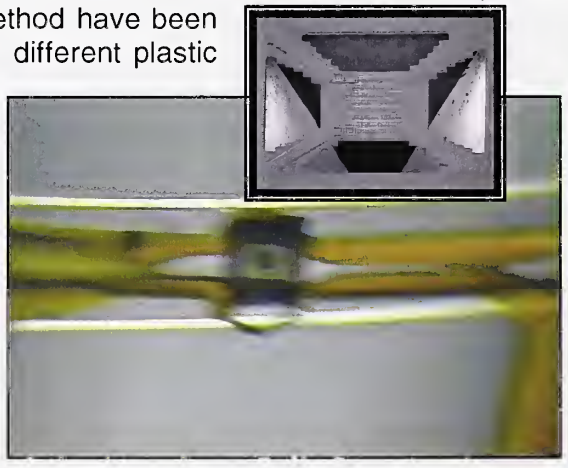
NIST/CSTL researchers are addressing the scientific and measurement issues involving microfluidic dynamic behavior, chemical selectivity, and detection that impede the development of "lab-on-a-chip" devices.

Microfluidic, or so-called "lab-on-a-chip", devices are generating much excitement because of their potential for high-speed and high-throughput chemical analysis relative to conventional bench top chemical instruments. Miniaturized devices for DNA separations have recently been commercialized for DNA sequencing. However, expansion of the "lab of the future" to other applications is held back by numerous technical barriers, such as poorly characterized and nonreproducible microfluidic behavior, the high cost of silicon-based devices, and the lack of integrated and chemically selective detection elements.

Raised silicon are used to imprint channels in plastic



NIST researchers have successfully made microfluidic channels in a number of different plastics. An optical-based method and current-monitoring method have been implemented to measure electro-osmotic mobility in different plastic devices. Such fundamental data relating flow to surface properties will enable developers of this technology to tailor plastic microfluid channels for specific applications. We have studied the effect of imprinting methods for channel fabrication and the effect of these procedures on wall charge. In addition, the team has modified flow in microchannels using polyelectrolyte multilayer surface modification. To date, the NIST team has fabricated integrated electrodes (Au/Cr), and integrated silicon microheating elements into microfluidic channels for use as flow sensors.

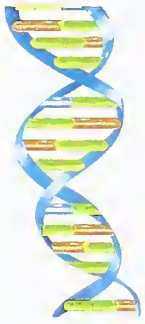


First hybrid device with integrated silicon elements in plastic microfluid systems

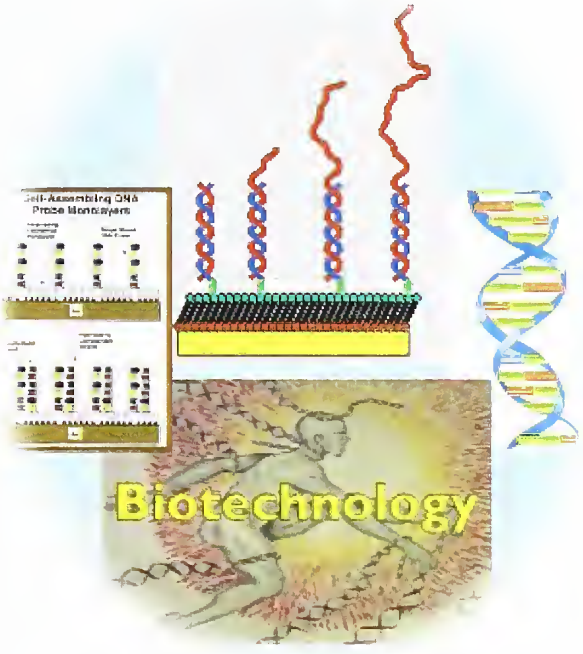
DNA Sensors

"BY 2005, DNA probes are expected to account for $6 billion, or 15%, of a $40 billion in-vitro diagnostics market."

ATP White Paper



DNA array technologies are being used for a variety of applications including drug discovery, characterization of genetic and infectious diseases, and cancer diagnosis. Although the impact of these devices is likely to be revolutionary, the fundamental factors affecting the hybridization of surface confined DNA in these arrays are still not well understood. The objective of this NIST/CSTL research is to determine how DNA surface coverage, molecular orientation, DNA structure and sequence identity impact the functionality of DNA array devices, and to elucidate potential enhancements. To study these factors we use a model system developed at NIST with short sequences of single-stranded DNA probes self-assembled on gold surfaces through a thiol linker. The gold is then passivated with mercaptohexanol to eliminate non-specific adsorption of DNA to gold and to significantly enhance the activity of immobilized probes. Complementary single-stranded DNA targets in high salt, buffered solutions hybridize with relatively high efficiency (25-100%) to these surface bound probes.



An automated surface plasmon resonance (SPR) instrument, constructed and programmed at NIST, determines the nanometer-scale thickness changes associated with surface hybridization reactions. We study how variations in probe surface structure, the length of ssDNA targets, and the relative position of the complementary sequence in the ssDNA targets affect hybridization efficiencies and kinetics. Our results indicate that with longer targets the efficiency of hybridization falls dramatically, a factor that must be considered when using DNA chip arrays for quantitative applications.

A Centennial Scrapbook
remembering the past ... a key to the future

Dignitaries gather for the groundbreaking of state-of-the-art laboratories:

Left: The new chemistry building on the Connecticut and Van Ness site in Washington DC Fall 1915

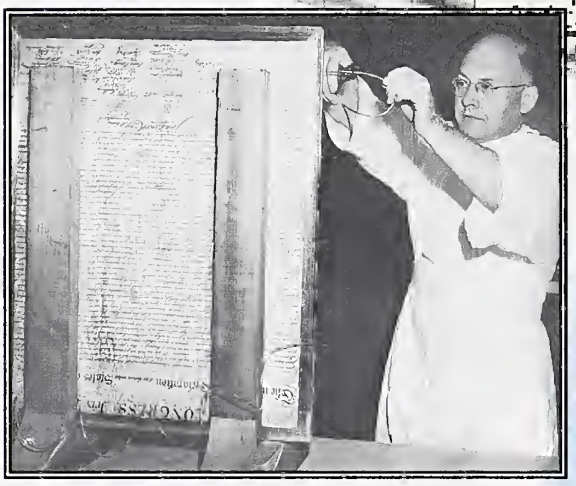
Right: Federal and local officials break ground for NIST's new Advanced Measurement Laboratory, June 2000

This institute has a rich history of membership and leadership in international standards organizations and committees to help ensure that our standards, and U.S. manufactured products, are globally accepted.

Left : International Technical Committee Members of 1910

Below: CCQM Members of 1999

Charters of Freedom:



The Declaration of Independence, the Constitution and the Bill of Rights (on permanent display at the National Archives in Washington, DC) have guaranteed the rights and freedoms of Americans for more than 200 years. Since 1951, these great documents--known collectively as the Charters of Freedom--have been preserved in helium-filled cases created by the Commerce Department's National Bureau of Standards, predecessor to the National Institute of Standards and Technology. Now, NIST, the National Archives and Records Administration, NASA and Heery International have teamed to design new state-of-the-art enclosures for the Charters of Freedom. ***CSTL researchers are NIST team members and supply expertise regarding the measurement of low-level impurities in gases.***

Deterioration of the glass in the current encasements appears as small surface cracks, crystals and droplets. This deterioration will eventually cause the glass to become opaque. Additionally, contact between the parchment and the glass may cause abrasions. Correcting these problems in the current cases is not possible: these cases are soldered shut and cannot be opened without compromising the seal.

Conservators will be able to be open and reseal the new cases—if it's ever necessary—to examine the documents or modify the interior components. The documents will be mounted so that glass never touches parchment. Ultra-smooth surfaces and the use of atomically larger argon gas rather than helium will prevent leakage. The new design will afford the flexibility to incorporate future conservation techniques as they are developed.

Working with Industry:

Standards for the Construction Industry:

In 1911 the cement laboratories of NBS tested over 23,900 samples, representing almost 2.5 million barrels of cement purchased for Government construction projects. The sampling required 512,000 physical tests, for fineness, specific gravity, tensile strength, and time of setting. … In many cases the Government specifications were far from clear. … In early 1912, the Bureau called manufacturers and Federal engineers to the first Portland Cement Conference, in order to consider preparation of a single standard specification. As a result, an Executive Order was issued in April of 1912, declaring that all portland cement purchases by the Government was to conform to the agreed upon specifications." (*Measures for Progress – A History of NBS)*

In 2000, ten new cement SRMs, certified for chemical composition, were produced by NIST in response to a continuing and increasing demand for cement standards. In the U.S., 45 companies and 118 plants in 37 states produce more than 80 million tons of cement yearly. This suite of SRMs is comprised of 6 different Portland cements, one white cement, one blended cement, and two different calcium aluminate cements. The SRMs are used by the industry primarily for production quality control in order to meet manufacturing specifications. Industry laboratories must demonstrate their competence to perform American Society for Testing and Materials (ASTM) Standard Test Methods, which require high levels of accuracy and repeatability, better than 1% relative for major components. Standards are also used for research and development related to strength, stability and durability of new products, and associated environmental concerns. As the variety of cement products grows, standards must cover a wide range of composition. One of the new SRMs contain slag and fly ash and addresses some of the environmental issues where cement production is viewed as an avenue for productive use of waste materials.

Standards for the Automotive Industry

By 1922 work in progress at NBS included research on automobile engines to find ways to increase their operating efficiency, … of power losses in automobile tires, *and reclamation of used lubrication oil.*

Automobile pictured to the right was used in the Bureau's famous study of the reaction times of drivers. (*History of NBS)*

Today, the **U.S. lubricants industry**, estimated to be worth $5 billion with a projected growth of about 5 % per year, has identified a standard certified for additive elements in passenger car motor oil as a top priority. The

new NIST *Lubricant Additive Package* SRM provides traceable standards for testing engine wear, and is needed for linking measurements made on finished products to national or international standards for compliance with ISO 9000 and QS 9000 requirements.

The U.S. automotive industry's long-term goal is to develop affordable mid-sized cars that are environmentally friendly and will travel the equivalent of 80 miles per gallon of gasoline. A NIST/Industry

collaboration resulted in the production of NIST's low concentration gas standards that allow verification of next generation vehicle emission. In addition, the NIST High Temperature Gas Flow Calibration Facility (pictured above) provides U.S. industry with a unique capability to test and evaluate flow meters used in emissions testing under realistic usage conditions of variable gas composition, temperature, and flow.

Between 1920 and 1930, the number of cars on the road rose from 9 to 26.5 million. Even at that time, it was believed that "the nation's supply of gasoline and oil must be conserved." Depletion of this country's known resources were said to be as little as 10 years away. The need for conservation, as well as improvement of the quality of available gasoline was unquestioned.

During the 1920's, in cooperation with the American Petroleum Institute, NBS issued a series of papers establishing the characteristics of efficient motor engines, fuels, and oils.
(History of NBS)

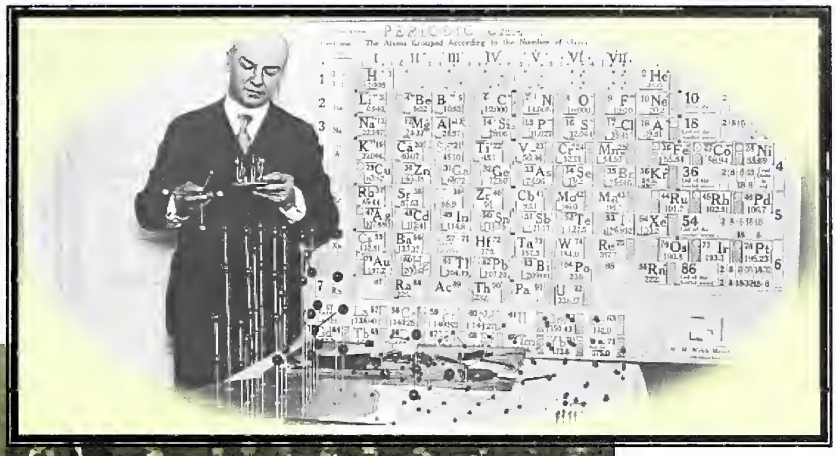
Fuel Standards: An economic impact of **Standard Reference Materials for *Sulfur in Fossil Fuels*** was completed in February 2000. The sulfur content of fossil fuels is one of the most important intrinsic factors that determine fuel prices. The accurate determination of the sulfur concentration in fossil fuels is required as a result of environmental regulation that places increasingly lower limits on their sulfur content and the imposition of large fines for non-compliance.

This impact study quantifies a portion of the economic benefits associated with these SRMs beginning in 1984, and projected through 2003. Surveyed industry representatives indicated that NIST SRMs have decreased the level of uncertainty associated with their measurements of sulfur content. This reduction has led to economic benefits throughout the supply chain. Included in the measures of economic benefits are improvements in product quality, production efficiency, and reductions in transaction costs and sulfur emissions to the environment. This study estimates a benefit-to-cost ratio of 113, and a social rate of return of 1,056 %. The Net Present Value was calculated to be more than $400 billion.

Technical Excellence:
The staff is the institute's greatest asset both past and present

Right: NBS scientist in the 1920s

Pictured below – seminar on the Gaithersburg Site in the late 1960's



Pictured in the collage to the right are some of CSTL's new hires, Post-Doctoral and Graduate Fellows

...the hope and promise for the future ...

In conclusion ... thanks to you
our customers and colleagues
collaborators, associates, and friends
for 100 years of stimulating technical interactions
and looking forward to continued partnerships in the 21st century and beyond...

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